Calhoun: The NPS Institutional Archive

DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

1969

An investigation of bottom changes in Monterey harbor (1932-1969).

Lennox, Richard John

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/12401

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

NPS ARCHIVE
1969
LENNOX, R.

AN INVESTIGATION OF BOTTOM CHANGES IN MONTEREY HARBOR (1932-1969)

by

Richard John Lennox

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5101

United States
Naval Postgraduate School

THESIS

AN INVESTIGATION OF BOTTOM CHANGES IN MONTEREY HARBOR (1932-1969)

by

Richard John Lennox

T132719

June 1969

This document has been approved for public release and sale; its distribution is unlimited.

AN INVESTIGATION OF BOTTOM CHANGES IN MONTEREY HARBOR (1932-1969)

by

Richard John Lennox
Lieutenant, United States Navy
B.S., Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
June 1969

~~Thesis~~
~~L458~~
~~c.1~~
NPS ARCHIVE
1969
LENNOX, R.

ABSTRACT

Bottom changes occurring in Monterey Harbor from 1932-1969 were analyzed by numerical computer methods using 15 selected hydrographic surveys. Results of the study indicate that the major portion of the harbor has been shoaling in the mean since 1932. The long-term shoaling rate has been 0.4 to 4.0 feet per decade in the beach and nearshore zones and along the breakwater; and less than 0.25 feet per decade in the stable outer harbor. The accretion rate averaged 17,500 cubic yards per year from 1932-1969 but only 7,100 cubic yards per year from 1947 to 1969. The shoaling is believed due to the construction of the Coast Guard Breakwater in 1931-1934. It is deduced that prior to 1960 the excess sand was carried into the harbor by littoral transport from Del Monte Beach and by wave currents around the breakwater. Construction of the solid wall on Wharf 2 in 1960 cut off the former sand supply. Local redistribution of sand in the beach and nearshore zones of the harbor is large and results in areas of significant accretion and erosion between surveys. Dredging operations have had only short-term effectiveness because the spoil has been retained within the harbor.

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIF. 93940

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5101

TABLE OF CONTENTS

Chapter	Title	Page
I.	INTRODUCTION	9
	A. PURPOSE AND SCOPE	9
	B. PREVIOUS BOTTOM-CHANGE STUDIES	12
	C. DESCRIPTION OF THE HARBOR	13
	1. Geography and Key Harbor Structures	13
	2. Geology and Sediments	13
	3. Currents and Waves	17
	a. Currents	17
	b. Waves	18
	D. HARBOR CONSTRUCTION AND DREDGING	19
II.	PROCEDURES	23
	A. HYDROGRAPHIC SURVEY REDUCTION	23
	1. Selection of Surveys	23
	2. Contouring and Grid Area	25
	B. COMPUTER ANALYSIS	28
	1. Depth Difference	28
	2. Volume Computation	28
	3. Long-term Bottom Changes	30
	C. HYDROGRAPHIC SURVEY CONDUCTED IN JANUARY 1969	31
	1. Equipment Used	31
	2. Position Fixing	32
	3. Depth Correction and Chart Construction	32
III.	BOTTOM CHANGES OBSERVED	34
	A. HISTORICAL BOTTOM CHANGES	34
	1. Comparison of Surveys	34
	2. Statistical Analysis	38
	a. Bottom Trends Between 1932-1969	43
	b. Bottom Trends Between 1947-1969	43
	c. Standard Deviation of the Depth	44
	3. Volume-Change Computations	45
	B. SEDIMENT REGIME AND THE EFFECTS OF HARBOR WORKS	49
	1. Sediment Regime	49
	2. Effect of Harbor Structures	52
	3. Effect of Dredging Operations	53
IV.	RECOMMENDATIONS	54
	A. SURVEY TECHNIQUES	54
	B. FURTHER STUDIES	54
	BIBLIOGRAPHY	55

Page

APPENDIX

A. Surveys 1 through 15 56

B. Survey Comparisons 1 through 16 72

C. Bottom-Trend Graphs 96

D. List of Charts of Monterey Harbor: 1851 to 1969 141

E. Computer Programs 147

F. Monterey Harbor Hydrographic Survey of January 1969 178

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Aerial Photograph of Monterey Harbor	10
2.	Monterey Harbor Location Map	11
3.	Location of Key Structures in Monterey Harbor	14
4.	Monterey Harbor Hydrographical Features	15
5.	Tidal Currents in Monterey Harbor	16
6.	Area of Study and Numerical Analysis Grid	26
7.	Scan Output: Contours of Bottom Change	29
8.	Bottom Trends 1932-1969	39
9.	Bottom Trends 1947-1969	40
10.	Standard Deviation of Depth, 1932-1969	41
11.	Standard Deviation of Depth, 1947-1969	42
12.	Graph of Cumulative Volume Change vs. Time	48

LIST OF TABLES

Table	Title	Page
I.	Significant Harbor Construction and Dredging	20
II.	Surveys Used in the Study	24
III.	Survey Comparisons	35
IV.	Volume Figures for Common Area	47

ACKNOWLEDGEMENTS

This investigator wishes to express his appreciation to the San Francisco District Office of the U. S. Army Corps of Engineers and to the Office of the City Engineer, Monterey, California for supplying the hydrographic and harbor-works data used in this study, and for their willing cooperation in various other ways. Appreciation is also expressed to the personnel of the computer facility and to the technicians of the Department of Oceanography. The faculty of the Oceanography Department is also thanked for their continued encouragement during the course of this study. Special thanks is extended to my advisor, Dr. Warren C. Thompson, whose time, efforts, and experience were invaluable aids in the conduct of this study.

I. INTRODUCTION

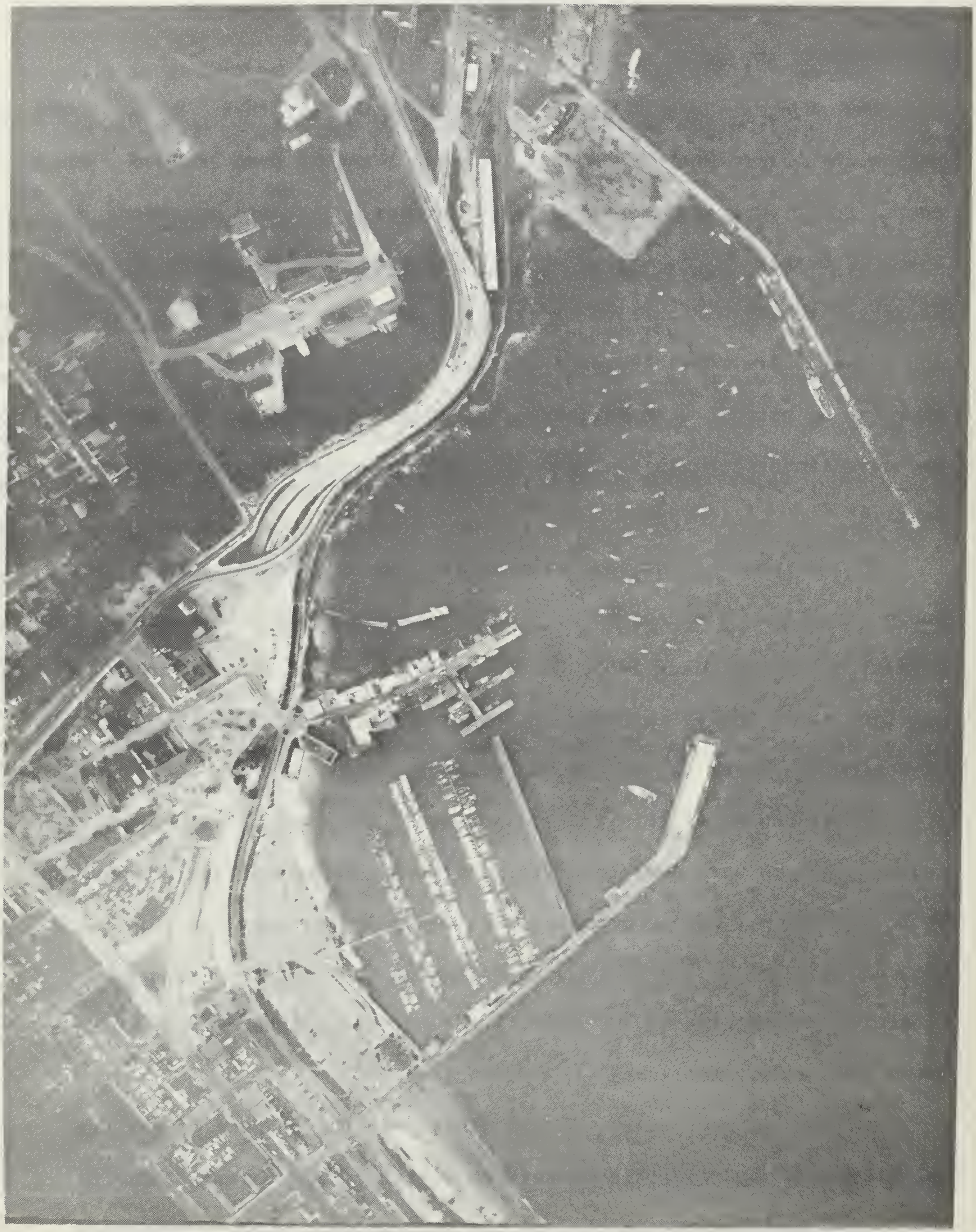
A. PURPOSE AND SCOPE

The objective of the research described in this thesis was to study bottom changes in Monterey Harbor (Figures 1 and 2) from 1932 to 1969 by comparison of successive hydrographic surveys. Specific questions of interest were: Is the harbor shoaling or eroding with time? If there has been long-term accretion or erosion, what are the sediment sources and losses? Are there seasonal changes or other patterned bottom changes that may be noted? What influence has local construction and dredging had on sedimentation in the harbor? Have dredging operations been effective?

The hydrographic surveys used in this study were all made by the Corps of Engineers except for the most recent one which was made by this investigator in January 1969. The latter survey was made in order to provide bottom-change information covering the period from the last Corps of Engineers survey in 1963 to the present.

In the course of this study a series of computer programs were developed which were used to contour surveys, to compute the changes in bottom topography and sediment volumes occurring between two surveys, and, using a series of surveys, to determine any long-term trends of erosion or deposition in any part of the harbor. These computer programs are readily applicable to other areas.

Limitations encountered in the study were the absence of sufficiently detailed hydrographic surveys of Monterey Harbor prior to 1932, the uneven distribution in time of the hydrographic surveys conducted from 1932 to 1969, and the poorly recorded data concerning dredging operations in Monterey Harbor carried out by the City of Monterey and the Corps of Engineers.



U.S. NAVY PHOTOGRAPH

Figure 1. Aerial Photograph of Monterey Harbor

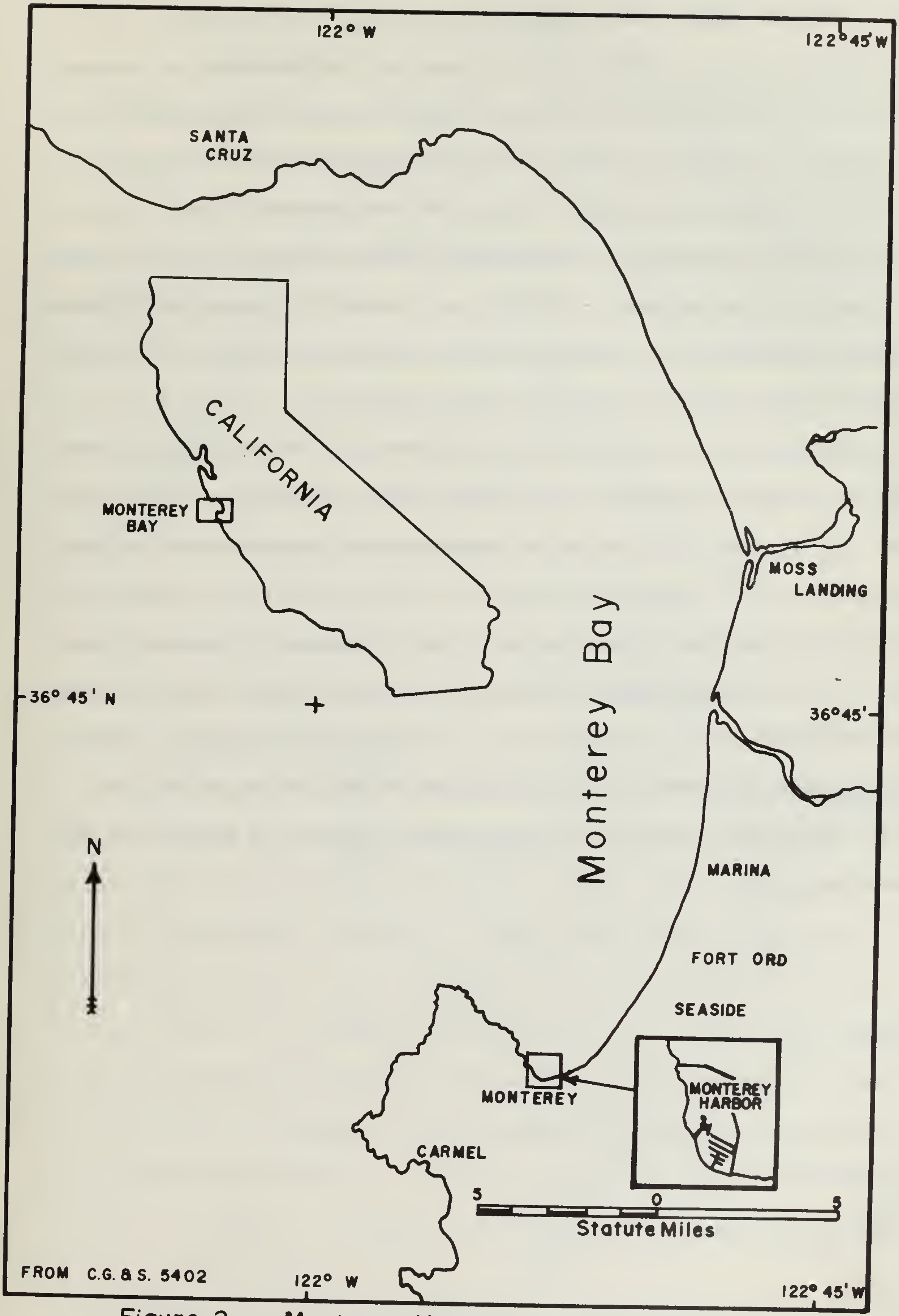


Figure 2. Monterey Harbor Location Map

B. PREVIOUS BOTTOM-CHANGE STUDIES

Two previous studies of bottom change and sedimentation in Monterey Harbor have been made by the Corps of Engineers. The first study is contained in a report on Monterey Harbor printed in House Document No. 266, 76th Congress, 1st Session, 1939, and was concerned with shoaling between Wharf 1 and Wharf 2 from 1932 to 1938 (see Figure 3). The report indicated that approximately 100,000 cubic yards of sediment was deposited between the wharves and attributed this accretion to littoral drift entering the area from the beach to the east of Wharf 2.

The second study by the Corps of Engineers is printed in House Document No. 219, 86th Congress, 1st Session, 1959, and deals with the period from 1851 to 1949. This study was prompted by a recommendation for the construction of a companion breakwater to extend out from Del Monte Beach to provide for a larger harbor. The findings of this report showed that the area between Wharf 1 and Wharf 2 was shoaling at the approximate rate of 14,000 cubic yards per year. It was believed that the proposed breakwater would serve to act as a barrier to this influx of sediment while not making significant changes to the coastline on either side of the harbor.

C. DESCRIPTION OF THE HARBOR

1. Geography and Key Harbor Structures

Monterey Harbor lies at the extreme southern end of Monterey Bay approximately sixty nautical miles south of San Francisco (Figure 2). The general shape of the harbor and location of key structures within the harbor are shown in Figure 3. The harbor is contained on the north by the Coast Guard Breakwater and on the west by a rocky shoreline extending from the breakwater to Wharf 1. The southern boundary between Wharf 1 and Wharf 2 is a sand beach which continues upcoast as the coastline of Monterey Bay. The eastern limit of the harbor is Wharf 2. There is a marina in the southern corner of the harbor enclosed by the frontal and east walls. The northern half of the harbor is used as a boat anchorage. Details of the harbor plan may be seen in the aerial photograph in Figure 1.

The general topography of the harbor bottom is shown in Figure 4; the hydrography shown is that of the January 1969 survey.

2. Geology and Sediments

The rocky shoreline between Wharf 1 and the Coast Guard Breakwater, and the rock outcrops in the shallow water in this area, are granodiorite of the Santa Lucia Formation (Cretaceous). The bottom in this area is sometimes covered with several feet of sand. The rock underlying the eastern side of the harbor in the vicinity of Wharf 2 is siliceous shale of the Monterey Formation (Miocene). The contact between these two lithologic structures is not exposed and its location is not accurately known. Elsewhere on the Monterey Peninsula the contact between these formations may be seen to be depositional (personal communication with Dr. Warren C. Thompson), but the proximity of the Tularicitos

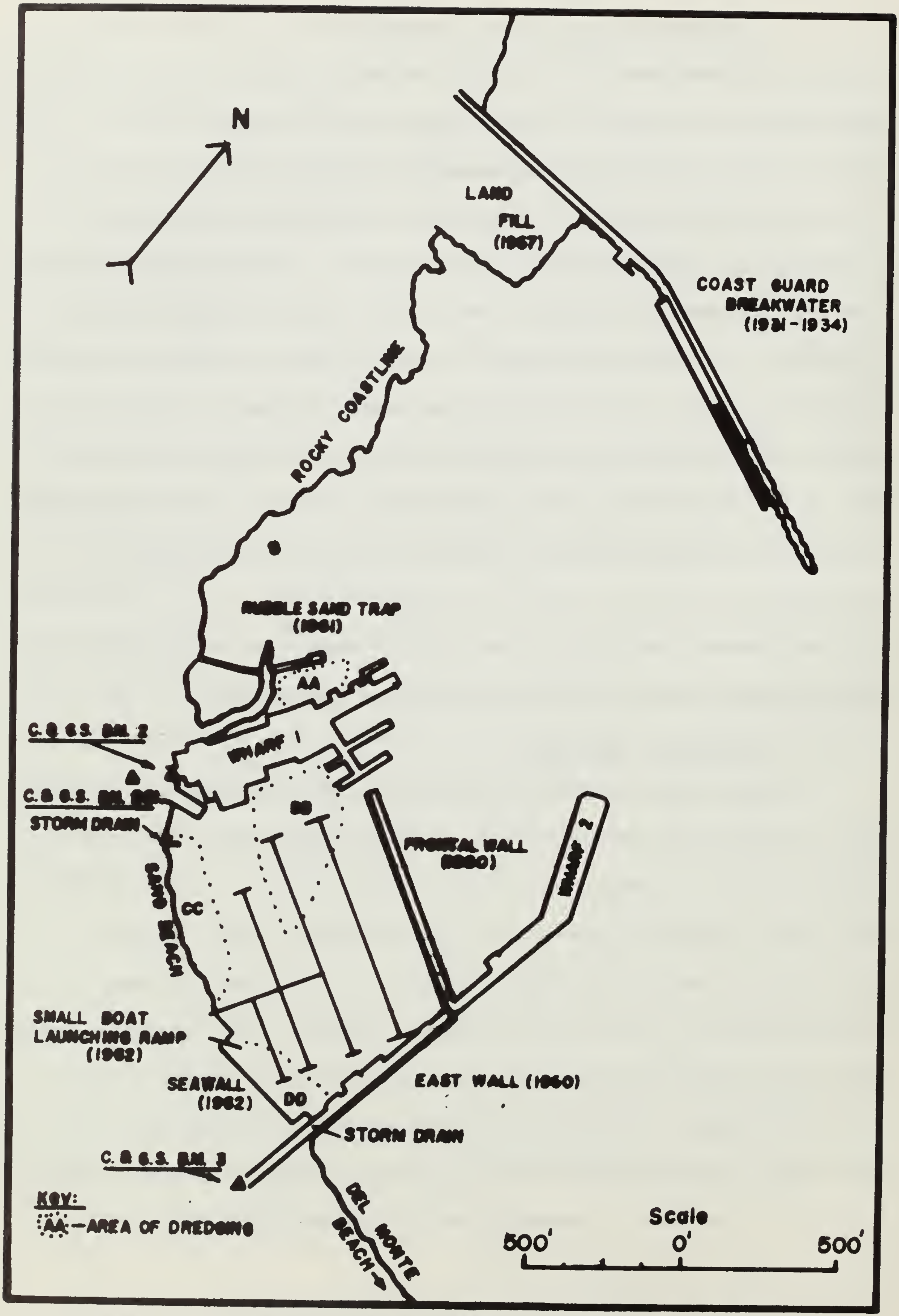


Figure 3. Location of Key Structures in Monterey Harbor

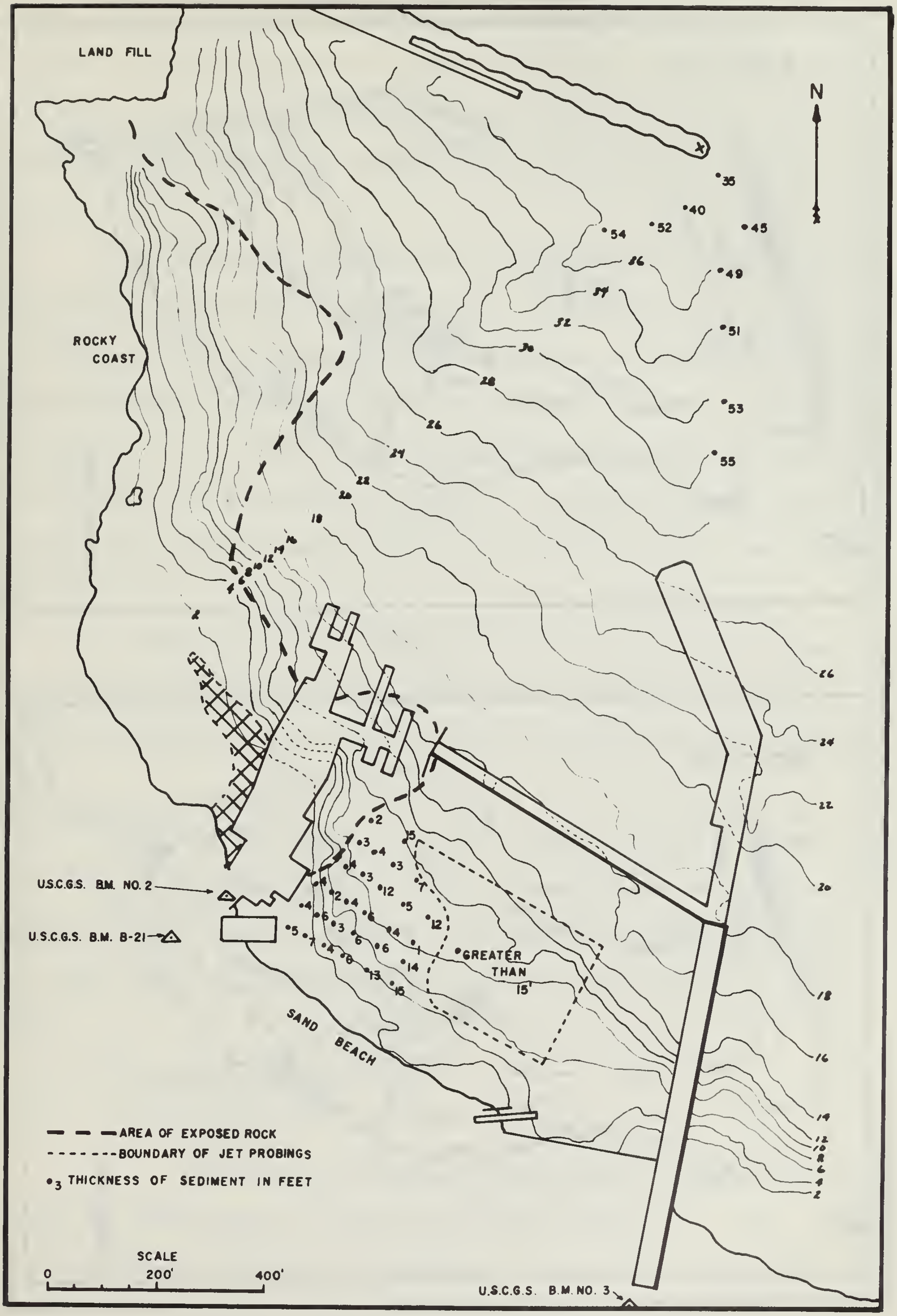


Figure 4. Monterey Harbor Hydrographical Features

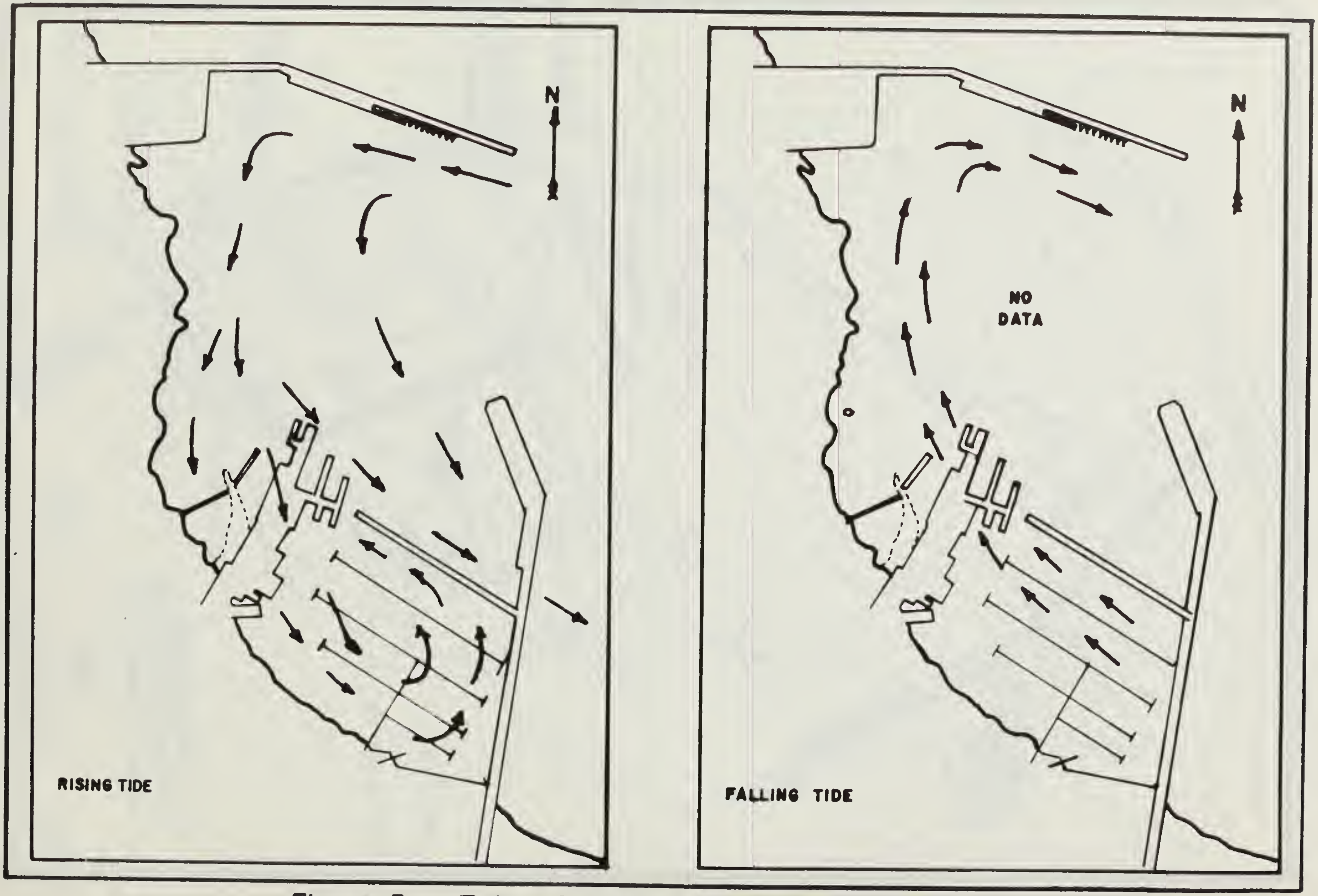


Figure 5. Tidal Currents in Monterey Harbor
(FROM BREIDENSTEIN & THOMAS, 1965)

Fault to Monterey Harbor (preliminary geological map provided by Robert S. Ford, California Department of Water Resources), could indicate that the contact in the harbor is an extension of this fault system. Thus, it is not clear whether the contact is of a depositional or faulted nature.

The thickness of sediments on the harbor floor is known over part of the harbor from observed outcrops, from borings made by the Corps of Engineers in 1947 (Corps of Engineers Drawing No. 6-13), and from sub-bottom profiles run by the Corps of Engineers in 1966 (Corps of Engineers Drawing No. 6-5-3). The area of exposed rock and the sediment thickness at the boring sites are shown in Figure 4. Immediately to the east of Wharf 2 the bottom is exposed shale in water depths greater than 15 to 20 feet.

Figure 4 shows that thick fill occurs on the bottom through the marina and the seaward end of the Coast Guard Breakwater. This is believed to indicate an old drainage channel extending out from El Estero Lake.

The sediment composition in the harbor was shown by Dorman (1968) to be fine sand on the beach and nearshore area between Wharves 1 and 2, medium to coarse sand from Wharf 1 to the Coast Guard Breakwater along the rocky coast, and a mixture of very fine sand and silt in the outer harbor.

3. Currents and Waves

a. Currents

Breidenstein and Thomas (1965) measured currents inside the harbor and found them to be tidally controlled (Figure 5). These currents are predominantly weak and it is therefore questionable as to whether they are a significant agent for the transport of sand within the harbor. Currents off the harbor and off Del Monte Beach immediately upcoast from the harbor are also reported to be weak. While these weak currents are unlikely agents for the transport of sand, they are of sufficient strength to carry silt-sized sediment into the harbor area.

Littoral currents on the beach just east of Wharf 2 are predominantly weak or non-existent as indicated by the Corps of Engineers (1959), Koehr, Rohrbough, and Thompson (1964), Hohenstein, Jaeger, and Jones (1965), and Dorman (1968). The lack of an appreciable accumulation of sediments against the upcoast side of the solid bulkhead portion of Wharf 2 (built in 1959-1960) confirms this conclusion. Through the use of hindcast wave and swell data prepared by National Marine Consultants (1960) and wave-refraction information provided by Dr. Warren C. Thompson, this investigator, in conjunction with LT Craig E. Dorman, determined that a weak net current in the upcoast direction exists at a point approximately 2 miles east of Wharf 2.

b. Waves

Monterey Harbor is so protected in the southern end of the bay that waves cannot reach it from the open ocean without undergoing extensive refraction. Wilson, Hendrickson, and Kilmer (1965) show through the use of refraction diagrams that swell arrival at the harbor is almost unidirectional from the north-northeast. Wind waves generated in the harbor area are uncommon but are occasionally produced by north winds blowing the length of the bay.

Storm waves resulting in damage to boats, structures, and the shoreline in and near the harbor were investigated by Bixby (1962), who described the synoptic characteristics of storms and their frequency of occurrence over the fifty-year period from 1910 to 1960. Bixby's investigation revealed that storm waves at Monterey Harbor are generated by two synoptic weather situations which he called Open Ocean Storms and Bay Wind Storms. Open Ocean Storms are generated by west to southwest winds blowing over long ocean fetches; the waves resulting are diminished considerably by refraction before they reach the harbor. Bay Wind Storms generate rough seas within the bay from the north. The configuration of the southern end of the bay is such that Bay Wind Storms may create significant littoral drift southward along Del Monte Beach toward the harbor. Bixby calculated the frequency of important Bay Wind Storms to be once every seven years.

D. HARBOR CONSTRUCTION AND DREDGING

Familiarity with the chronological sequence of harbor structures and dredging operations is essential for inquiring into their effects on bottom changes observed through the years. A listing of both harbor construction and dredging operations that are considered significant is presented in Table I. Figure 3 shows the location of the various structures and dredging areas.

It can be seen from Figures 2 and 3 that prior to the construction of the Coast Guard Breakwater (1931-1934) the only protection afforded the harbor from storm waves from the open ocean was its natural location in the lee of the Monterey Peninsula. After completion of the 1750-foot impermeable rubble breakwater by the Corps of Engineers, the harbor received added protection from the north. Additional protection of the inner harbor was gained upon completion of the east wall and frontal wall of the marina. This solid wooden bulkhead was built in 1959-1960.

TABLE I

SIGNIFICANT HARBOR CONSTRUCTION AND DREDGING

Refer to Figure 3 for the location of the below-mentioned harbor works.

Dates	Description
Dec 1931 - Mar 1934	Construction of the Coast Guard Breakwater.
Feb 1947	First major dredging in Monterey Harbor. Corps of Engineers dredged 58,520 cu yds of sand in areas AA and BB; spoil placed on beach between Wharves 1 and 2.
May 1950	Dredging by Corps of Engineers removed an unrecorded amount of sand from area BB and placed spoil on beach between Wharves 1 and 2.
Dec 1952 - Jan 1953	Healy Tibbits Construction Company dredged approximately 20,000 cu yds of sand from west side of Wharf 1 in area AA and placed spoil in beach area as fill.
Aug 1953 - Aug 1954	Dredging by Corps of Engineers removed 12,049 cu yds of sand from area BB placing spoil on beach area as fill.
May - Jun 1957	Dredging by Corps of Engineers removed 8,223 cu yds of sand from area BB and placed spoil in beach area.
Oct 1959 - Aug 1960	Construction of perimeter wall: East wall completed June 1960 and frontal wall completed Aug 1960.

Dates	Description
Jun 1961	Dredging by City of Monterey in southeast corner of marina moved approximately 2,000 cu yds of sand to outer harbor area in depths greater than 20 ft.
Oct 1961	Construction of Rubble Groin (sand trap) to west of Wharf 1.
Mar 1962	Dredging operations conducted by City of Monterey to remove sand between Wharves 1 and 2 in area CC; spoil placed in area of sand trap.
Apr 1962	Construction of Sea Wall in southeast corner of marina by Granite Construction Co.
Jun 1962	Construction of Small Boat Launching Ramp. Dredging operations in vicinity of ramp to fill promenade area behind new sea wall.
Apr - May 1963	Dredging in southeast corner of marina by Granite Construction Co. Approximately 4,000 cu yds of spoil placed behind sea wall in present promenade area.
Jun - Nov 1963	Dredging operations in vicinity of Small Boat Launching Ramp by City of Monterey. Unrecorded amount of spoil placed on beach and behind sea wall.
Jun - Aug 1964	Dredging operations by Granite Construction Co. removed approximately 12,000 cu yds of sand from marina area DD; spoil placed in

Dates	Description
	outer harbor and in area of rubble trap.
1965 - 1967	Dredging operations conducted by City of Monterey Harbor crew removed approximately 6,000 cu yds of sand from boat tier area of marina; spoil used to replace depleted beach between Wharves 1 and 2.
Jan 1967	Dredging operations conducted by City of Monterey removed 23,000 cu yds of sand from area between Wharves 1 and 2; spoil was used as fill for the northwest corner of the harbor.

Note: Intermittent dredging by the Monterey Harbor Maintenance Crew has removed an unrecorded amount of sand from the beach between Wharves 1 and 2 at low tide. This spoil was redistributed on this same beach above the high water line.

II. PROCEDURES

This section of the thesis describes the hydrographic surveys, the delineation of the boundary of the area of study around the harbor, and the procedures used for handling the data. A portion of this section is also devoted to the hydrographic survey of Monterey Harbor made by this investigator in January 1969.

A. HYDROGRAPHIC SURVEY REDUCTION

1. Selection of Surveys

Fifty-six hydrographic surveys of the harbor and the bay immediately adjacent covering the time span from 1851-1969 are known to have been made, all of them except the one made by this investigator in 1969 having been conducted by the Corps of Engineers and the Coast and Geodetic Survey. A list of these surveys is contained in Appendix D.

These charts vary greatly in scale, sounding density, accuracy of depth measurement, and areal coverage of the harbor; accordingly, selection was made of charts which provide sufficient coverage and depth information. The criteria for selection were as follows: (1) The survey had to cover essentially the entire harbor; partial surveys were not considered. (2) The scale of the survey could be no smaller than 1" = 200'. (3) There had to be a sufficient density of soundings within the harbor area so that depths could be interpolated accurately at fifty-foot grid points. When these criteria were used, the original 56 charts were reduced in number to only 14 Corps of Engineers charts covering the period 1932 through 1963 and the 1969 survey made by this investigator. The 15 surveys have been numbered chronologically from 1932 (Survey 1) to 1969 (Survey 15). The survey number, survey date, scale, and identification of the 15 surveys are listed in Table II.

TABLE II

SURVEYS USED IN THE STUDY

Survey Number	Survey Date	Scale	Corps of Engineers Drawing Number
1	1932 AUG	1" = 50'	6-2-12
2	1934 MAR	1" = 200'	6-2-13
3	1935 JUL	1" = 200'	6-2-14
4	1935 OCT	1" = 200'	6-2-15
5	1937 SEP	1" = 200'	6-2-16
6	1938 JUL	1" = 200'	6-2-17
7	1945 NOV	1" = 200'	6-9
8	1947 JAN	1" = 200'	6-12
9	1948 FEB	1" = 200'	6-14, 6-2-21
10	1949 JUN	1" = 200'	6-18, 6-2-22
11	1951 SEP	1" = 100'	6-22, 6-2-23
12	1952 MAR	1" = 100'	6-23, 6-2-24
13	1954 AUG	1" = 100'	6-26, 6-2-26
14	1963 AUG	1" = 100'	6-2-31
15	1969 JAN	1" = 100'	None

*Survey No. 15 was made by this investigator on 22 and 29 January 1969.

The scales of the 15 charts used included 1" = 50' (1932 survey), 1 " = 100', and 1" = 200' (mainly in 1930's and 1940's). For this work, the most desirable of the three scales is 1" = 50' because it provides the greatest sounding density and accordingly allows the most accurate interpolation of water depths at selected grid points. It was felt that by careful contouring, the depths at fifty-foot grid points on the 1" = 200' scale charts could be interpolated to an accuracy of 0.1 foot.

2. Contouring and Area Grid

The Corps of Engineers surveys as received were contoured at six-foot intervals. All of the charts used in this study were carefully recontoured by hand by this investigator to a one-foot interval.

Upon completion of the contouring, a north-south oriented fifty-foot square grid covering the area of study was established for extracting the depth information from the surveys for use in a computerized format. Figure 6 shows how the grid system was superimposed upon the harbor, and indicates the locations of three Coast and Geodetic Survey Tidal Bench Marks used to insure the exact placement of the grid on individual charts.

The area investigated in this study is delineated by the irregular heavy line shown in Figure 6. This area varies slightly for different surveys because of the lack of sounding information in one or more sections of the harbor. The boundary of the area used for each survey comparison may be seen in Appendix B.

Following placement of the grid on a contoured chart, a depth value was read at each grid point contained within the area of study. These depth values were interpolated to 0.1 foot using linear interpolation between contours. The total number of grid-point readings varied

from 1544 to 1211 according to the area actually covered by each survey comparison as shown in Appendix B. These depth values were then placed on computer cards and were run through an initial computer program which provided a reduced number of data cards for easier handling, and a printout of the depth values. The printed output of depth values provided a means of checking to be sure that the proper depth values were associated with the proper grid points.

The computer also reproduced the 15 charts from these depth data for illustration purposes, and these are shown in Appendix A. The machine-drawn contours are plotted at a two-foot depth interval because of the chart scale.

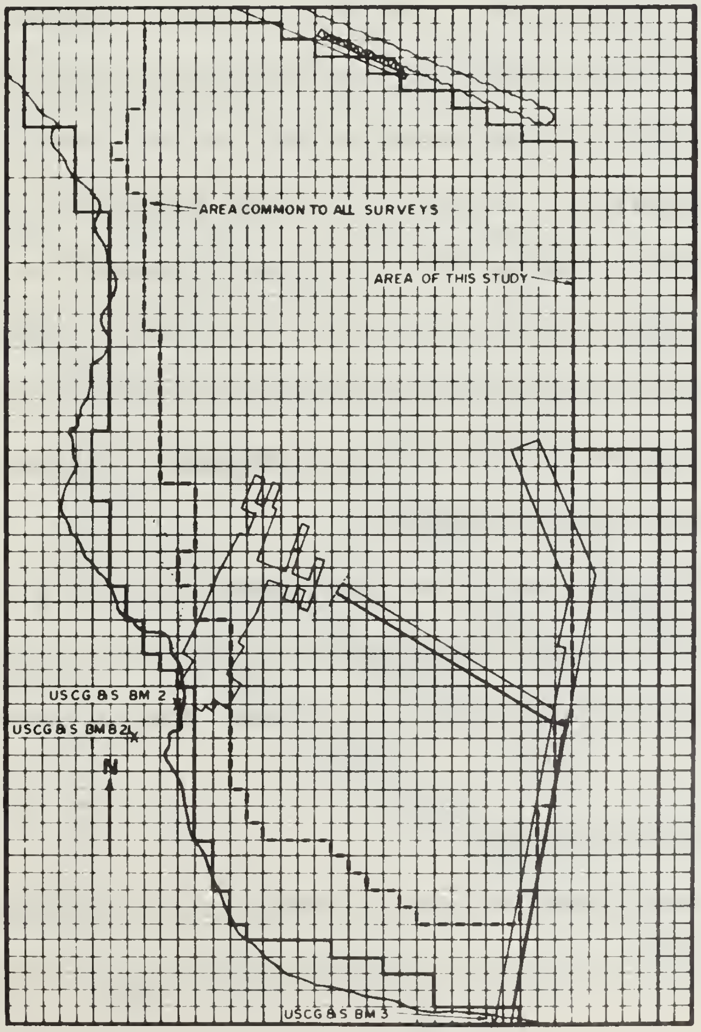


Figure 6 Area of Study and Numerical Analysis Grid

B. COMPUTER ANALYSIS

The comparison of one hydrographic survey with another was done using numerical techniques with the aid of a computer. The steps taken in handling the hydrographic data are explained below. Copies of the programs used may be found in Appendix E along with a brief explanation of their application.

1. Depth Difference

In order to obtain the change in depth at each grid point the data decks for the two surveys to be compared were placed in the computer using Program DIFFERENCE. Program DIFFERENCE provides an output in two forms. The first output is in the form of data cards which contain the depth-change values. This information was used as the input for subsequent programs and subroutines. The second output, constructed by Subroutine METMAP, is a printed numerical output in the form of a contoured map of the depth changes in the harbor between the two surveys. It was used for a gross analysis of the areas of change and is not illustrated.

A second program, SCAN, was used to produce a contour map of harbor bottom changes occurring between two surveys. Figure 7 is an example of the output of the Program SCAN and shows contoured changes indicating areas of accretion and erosion. The charts contained in Appendix B were drawn using this program.

Program SCAN and Subroutine METMAP may also be used to plot contours of the bottom directly using any desired contour intervals. Appendix A is an example of contouring with Program SCAN at two-foot intervals.

2. Volume Computation

Program VOLUME was used to obtain the volume change between

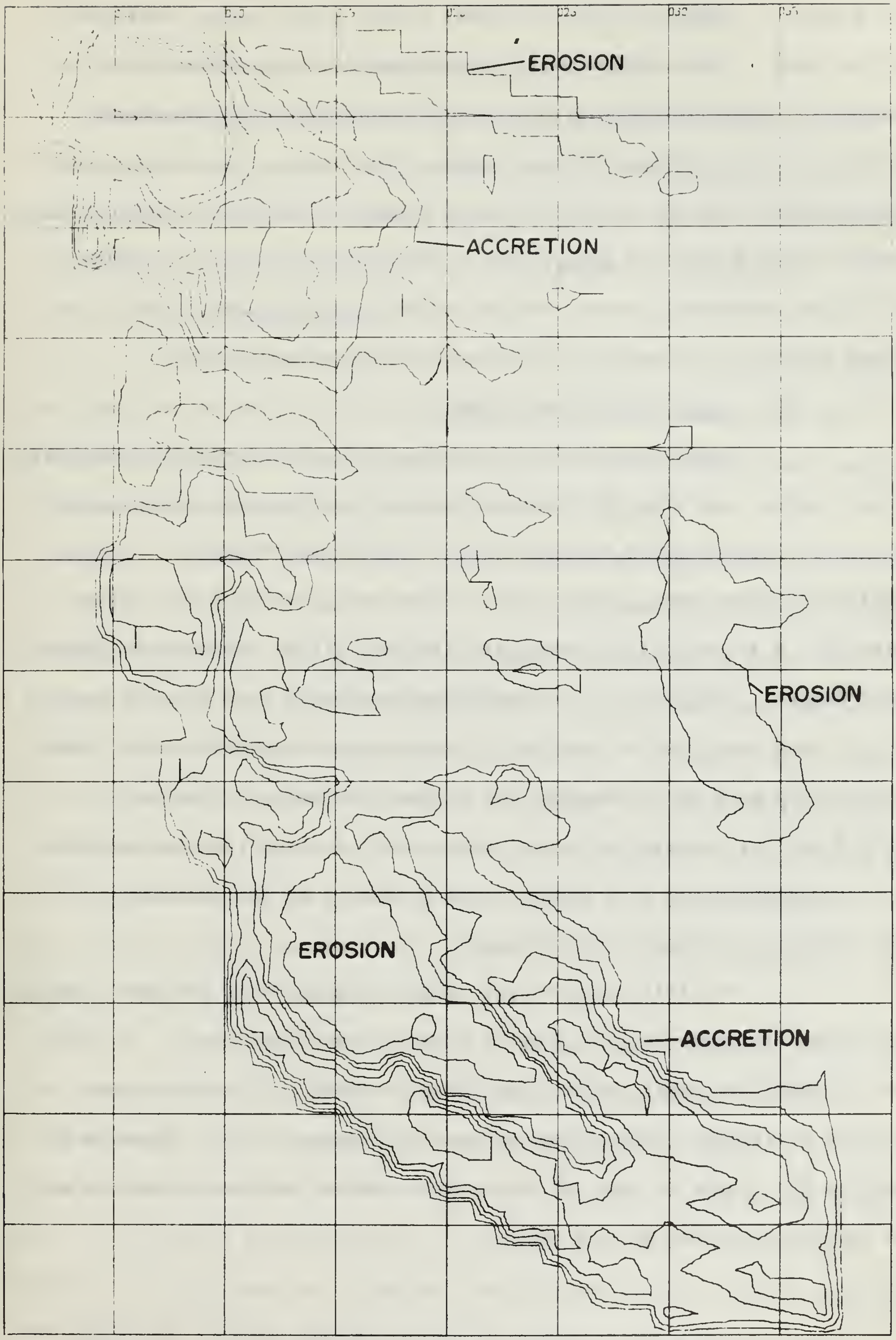


Figure 7. Scan Output: Contours of Bottom Change

two surveys. VOLUME uses the data-deck output from Program DIFFERENCE as its input. The program first determines an average value of depth change for each fifty-foot grid square by averaging the depth changes given at the four corners of each square. The average depth change was then multiplied by the area of the grid square to obtain the volume change between surveys for that grid square. The program concludes by adding all of the individual volume changes in the area of study to give a net volume change in the harbor for the period between the surveys.

3. Long-Term Bottom Changes

Long-term trends of shoaling and erosion in different parts of the harbor, and also the standard deviation of the water depth about the trend, were obtained through the use of Program STATISTIC. Program STATISTIC plotted water depth versus survey dates for each grid point selected. A least-squares regression line was fitted through the plotted water depths. The slope of the resulting regression line gives a measure of long-term rate of shoaling or erosion at a specific point. The program then goes on to compute the standard deviation of the water depth from this regression line at each point on the grid. The standard deviation computed in this manner gives a measure of the variability of each survey at the various grid points.

For this study 44 grid points located on a 250-foot spacing were chosen to represent the area of study in Monterey Harbor. The location of these 44 points and the resulting contours of all trends and standard deviations computed may be seen in Figures 8 - 11. Appendix C contains the graphs of each of the 44 grid points, and an explanation of the information found on each graph.

C. HYDROGRAPHIC SURVEY CONDUCTED IN JANUARY 1969

On January 22 and 29, 1969 the final hydrographic survey used in this study was conducted. This section reviews the equipment used in making the survey, the methods of fixing position, and the construction of the final plotted chart. The survey is shown in Appendix F.

1. Equipment Used

The Boston Whaler owned by the Naval Postgraduate School was used for the survey. This boat has a draft of 7 inches with two operators on board and was extremely useful for surveying in very shallow depths adjacent to the rocky shoreline and the beach.

Water depths were recorded using an Apelco Portable Recording Depth Indicator (Model MR-201 B). This instrument gives depth readings simultaneously on a lighted scale and on electrically sensitive chart paper. The accuracy of the depth recorder in depths less than 80 feet is specified by the manufacturer to be one percent. In order to be certain that the recorder remained calibrated throughout the survey frequent bar checks were made. The bar checks consisted of lowering a 3-foot metal bar in a horizontal position to pre-measured depths below the transducer. The results of these checks indicate that, with the boat stationary, the accuracy was better than one percent.

The depth transducer was mounted on the transom close to the outboard motor (7½ H.P.). It was found that with the transducer located in this position and the motor operating at idling speed the effects of vibration from the motor and the turbulence caused by the boat's wake were found to be negligible. The survey runs were therefore conducted at idling speed which assured the greatest possible depth accuracy. The latter was further assured by the fact that the harbor was calm on both dates of the survey.

2. Position Fixing

The tracks followed in sounding the marina were laid out on a City of Monterey Department of Public Works chart [Drawing No. 1562 (1960)], and the tracks for sounding the remainder of the harbor and the adjacent bay were laid out on a Corps of Engineers chart [Drawing No. 6-2-30 (1963)]. These were the latest charts available for the harbor. Positioning of the survey lines inside the marina is considered to be accurate to within one foot since many check points were available. The tracks followed in the open harbor area are considered to be accurate to within five feet. While there are not as many check points in the outer harbor area, it will be noted in the survey shown in Appendix F that where the track lines crossed one another the depths recorded at these crossings are in close agreement.

3. Depth Correction and Chart Construction

Upon completion of the field survey, a correction was applied to the depth record to account for the depth of the transducer below the water surface. The correction amounted to seven inches when two operators were in the boat and five inches if only one operator was aboard. The depth data were then reduced to the Mean Lower Low Water datum using tide records from the Standard Recording Tide Gage maintained on Wharf 2 by the Naval Postgraduate School. Depths at intervals along each track were then plotted on a base chart of scale 1" = 100'.

The base chart used was the Corps of Engineers Drawing No. 6-2-30. The shoreline placed on the chart is the Mean Lower Low Water shoreline obtained partially from the survey and partially from an aerial photograph (Figure 1) taken on February 10, 1969 by Commander Claude F. Giles of the Naval Postgraduate School. The shoreline in the aerial photograph was corrected for the tide and beach slope to get the Mean Lower Low Water shoreline.

III. BOTTOM CHANGES OBSERVED

Analysis of the bottom changes that occurred in Monterey Harbor from 1932 to 1969 was made using the fifteen surveys listed in Table II. These surveys are too numerous to be presented in the text and may be found in Appendix A. The objectives were to examine the surveys chronologically to determine the locations and amounts of change that have occurred in the bottom, and to examine possible causes of the changes observed. An additional objective was to determine whether or not seasonal changes occur in the bottom by comparing the surveys during selected months of the year. This latter method of comparision did not give conclusive results and therefore will not be illustrated.

A. HISTORICAL BOTTOM CHANGES

1. Comparison of Surveys

Sixteen survey comparisons were made and these are listed in Table III. Charts showing the depth changes between the surveys listed are presented in Appendix B because of the large number involved. Examination of the depth-change charts indicates that significant changes occurred in the harbor from survey to survey during the period from 1932 to 1969. The following general observations may be made when looking at Survey Comparisons 1 through 14. There appears to be four areas of distinctive bottom activity within the harbor. Two of these areas are located in the nearshore zone, the third area is located in the lee of and directly adjacent to the Coast Guard Breakwater, and the final area is the central outer harbor.

The first nearshore area to be discussed includes the beach and shallow-water zone between Wharf 1 and Wharf 2. This beach area experiences large reversals of accretion and erosion and is continually

TABLE III

SURVEY COMPARISONS

Survey Comparison	Survey Compared	Survey Dates	Number of Months Between Surveys
1	1-2	AUG 32 - MAR 34	19
2	2-3	MAR 34 - JUL 35	16
3	3-4	JUL 35 - OCT 35	3
4	4-5	OCT 35 - SEP 37	23
5	5-6	SEP 37 - JUL 38	10
6	6-7	JUL 38 - DEC 45	88
7	7-8	DEC 45 - JAN 47	14
8	8-9	JAN 47 - FEB 48	11
9	9-10	FEB 48 - JUN 49	16
10	10-11	JUN 49 - SEP 51	27
11	11-12	SEP 51 - MAR 52	6
12	12-13	MAR 52 - AUG 54	29
13	13-14	AUG 54 - AUG 63	108
14	14-15	AUG 63 - JAN 69	65
15	1-15	AUG 32 - JAN 69	436
16	8-15	JAN 47 - JAN 69	264

changing. Survey Comparisons 1, 2, 4, 5, and 6 indicate periods during which the predominant bottom change in this area was accretion. Survey Comparisons 4 and 6 are especially noteworthy in that the amount of shoaling is very large, with the values of fill reaching 10.7 and 10.6 feet, respectively. Survey Comparisons 3, 7, 10, 11, and 14 all indicate a predominance of erosion in the beach area, with the noteable comparisons being 3, 7, and 14 with depths of cutting of 8.0, 10.8, and 8.2 feet, respectively. The remaining Survey Comparisons 8, 9, 12, and 13 exhibit both shoaling and erosion. Survey Comparison 7 is particularly interesting because it shows extensive erosion of the nearshore zone with concurrent accretion on the beach. Local onshore-offshore exchange of sand between surveys is exhibited on several of the other comparison charts.

The second nearshore area is the rocky coastline from Wharf 1 to the Coast Guard Breakwater, extending out into the harbor 500-700 feet. The bottom changes there exhibit a pattern of alternating patches of accretion and erosion. The patches are highly irregular and suggest local exchange of sand along the shoreline rather than onshore-offshore exchange. The amounts of erosion and accretion for the most part vary in all survey comparisons between a maximum cut of 6.8 feet and a maximum fill of 7.4 feet, exceptions to this being Survey Comparisons 6 and 12 which show fills of 11.0 and 8.5 feet, respectively.

The third area noted is the narrow zone adjacent to the Coast Guard Breakwater. This zone has also experienced alternating accretion and erosion with time. Survey Comparisons of particular interest concerning this area are 1, 4, 5, 10, and 14, which reveal shoaling on the inside of the breakwater. These comparisons, particularly Comparison 14, suggest that an occassional influx of sand into the harbor may take place around the end of the breakwater from the small beach on the seaward side. Comparisons 2, 3, 6, 9, and 12 primarily indicate erosion. The remaining comparisons show either small patchy areas of erosion and shoaling or else a lack of activity.

The final area is the central outer harbor, which has remained relatively inactive throughout the 36.6 year period covered by the study. This investigator has made numerous Scuba dives in this area over the period from January 1967 to February 1969 and has found the bottom to be primarily very fine sand or silt with some rock outcrops in the area adjacent to the marina entrance (Figure 4). It was also noted during these dives that coarse litter on the bottom remained virtually unchanged with respect to sediment accumulation during this period. Personal consultations with members of the City of Monterey Harbor Maintenance Division indicate that the same observation has been made by divers since at least 1945.

The two additional survey comparisons analyzed are Survey Comparison 15 which covers the entire period of the study and Survey Comparison 16 which covers the period from 1947 to the present. The latter comparison was made in light of the large discontinuity noted in the volume-change graph (Figure 12), which will be discussed later in this chapter.

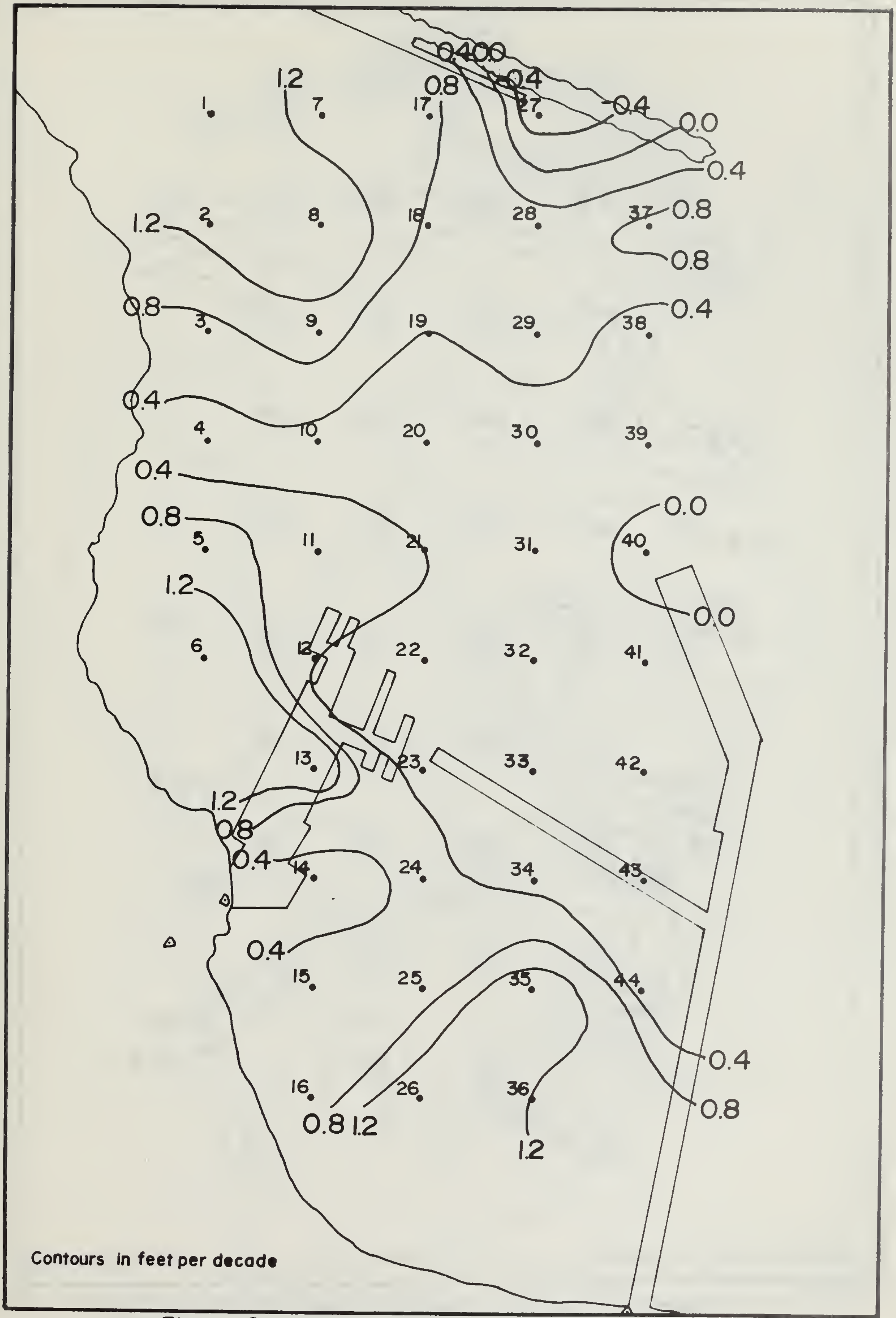
Survey Comparison 15 indicates a long-term trend in the harbor toward shoaling everywhere with the excpetion of two areas which indicate no change. The latter are the central harbor area in the vicinity of the frontal wall and Wharf 2, and the area just off the rocky coastline to the north of Wharf 1. This latter area points out a limitation in the use of these chart comparisons in that this area was indeed active over the entire span of the study as shown by Comparisons 1 through 14.

Survey Comparison 16 generally shows accretion, although a large area of erosion is indicated in the beach and shallow-water area between Wharves 1 and 2, and smaller areas of erosion may be noted along the rocky shoreline between Wharf 1 and the Coast Guard Breakwater. Again it should be kept in mind that the amount of change shown at any given location in the harbor gives the depth difference between two specific surveys and does not necessarily represent the long-term trend at that point.

2. Statistical Analysis

Examination of the survey comparison charts (1-14) over the period 1932-1969 suggests that, although the bottom charts generally show alternating periods of accretion and erosion at most locations in the harbor, the mean change over the period was that of accretion. In order to verify this observation, it was decided to determine the long-term bottom trend throughout the harbor. It was stated earlier that at 44 points in the harbor on a 250-foot grid values of the mean rate of depth change and standard deviation of the depth over a period of years were determined and are contoured in Figures 8-11.

The information contained in these figures will be described in three parts. The first part will present regression-line data computed for all surveys from 1932 to 1969. Because a marked discontinuity in bottom depths in the shallow parts of the harbor occurred between the surveys of 1938 and 1947 (discussed in Section 3 below), a second regression line was fitted to the survey points covering the period from 1947 to 1969. The results of this analysis are treated in the second part.



Contours in feet per decade

Figure 8. Bottom Trends 1932 - 1969

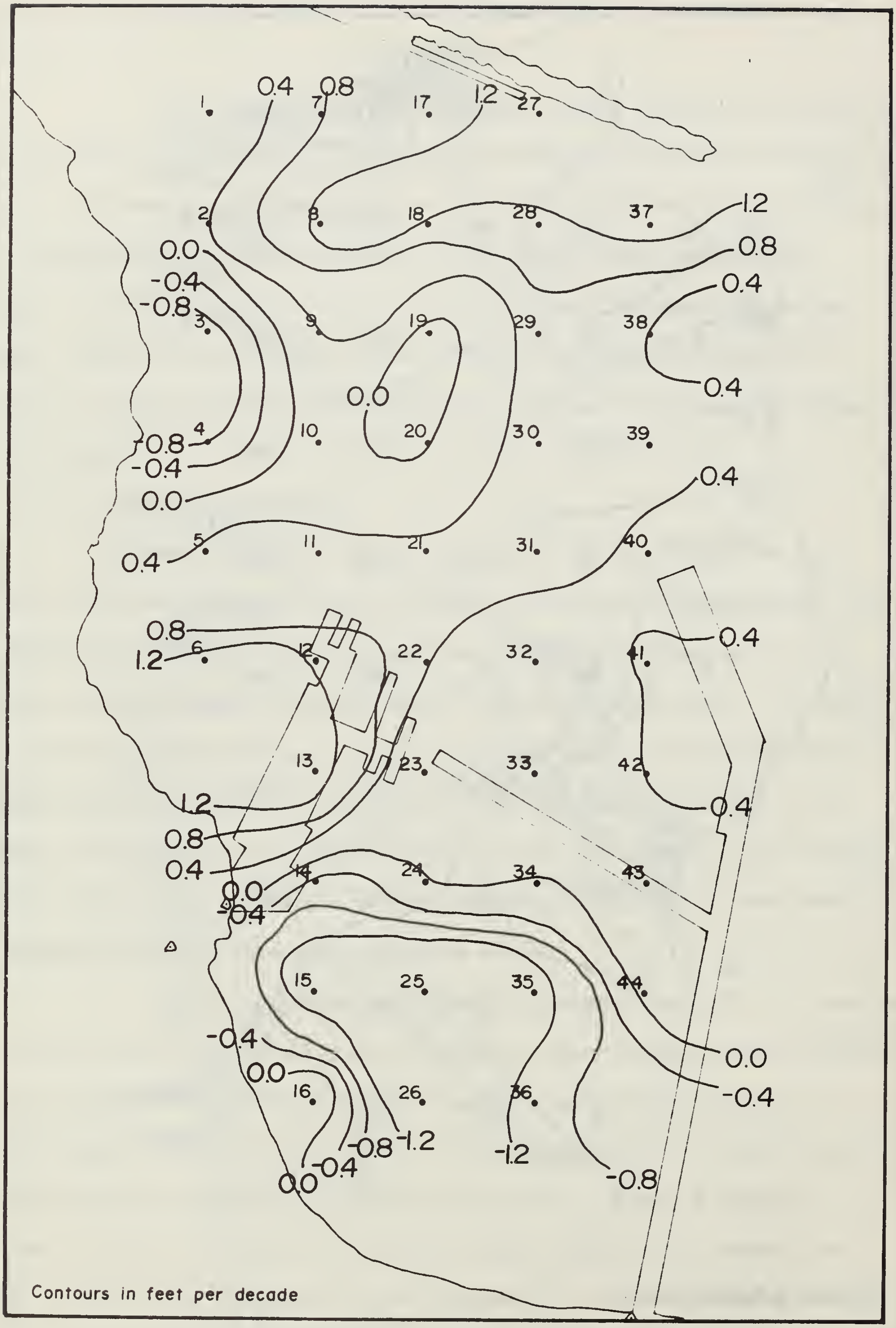


Figure 9. Bottom Trends 1947-1969

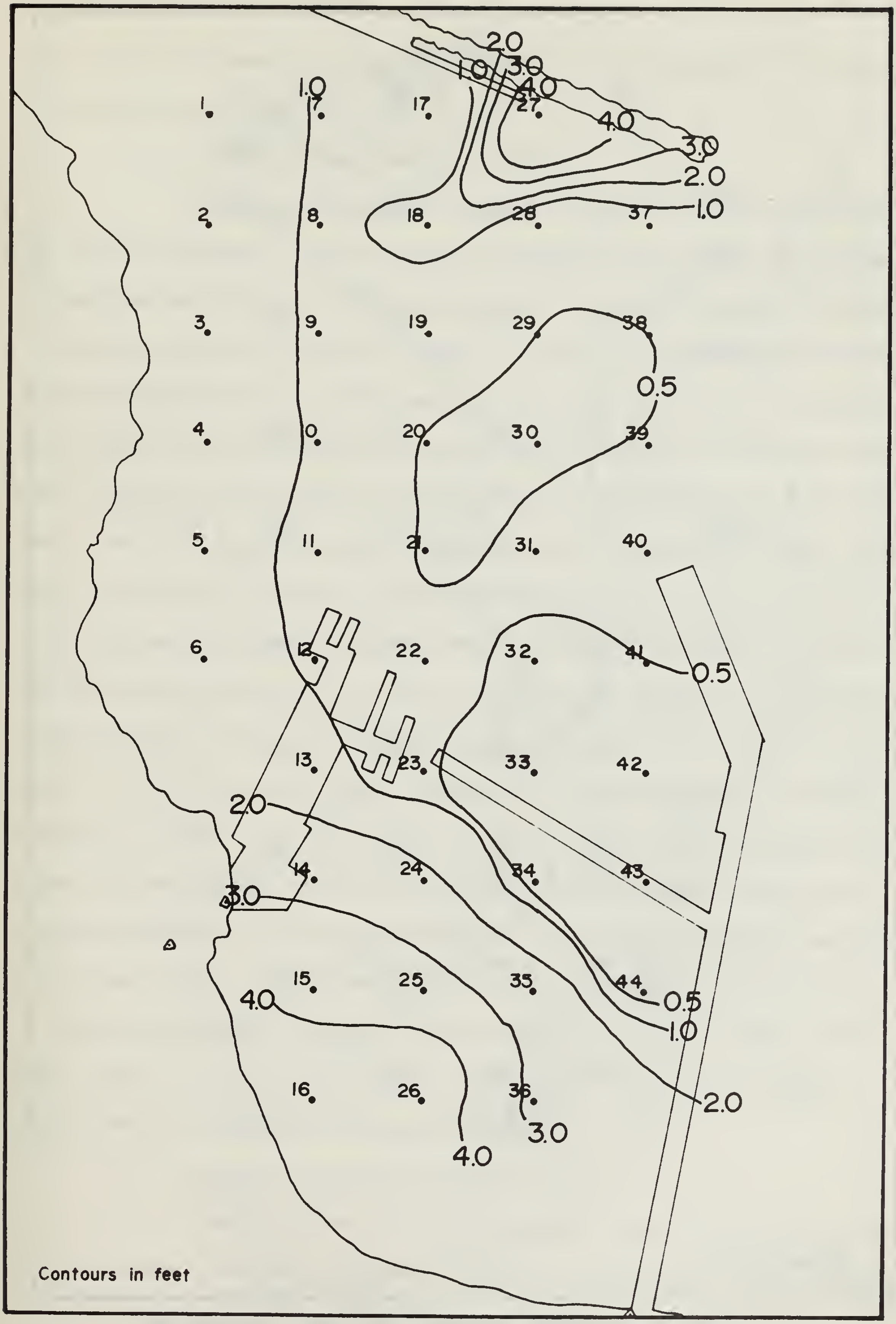


Figure 10. Standard Deviation of Depth 1932-1969

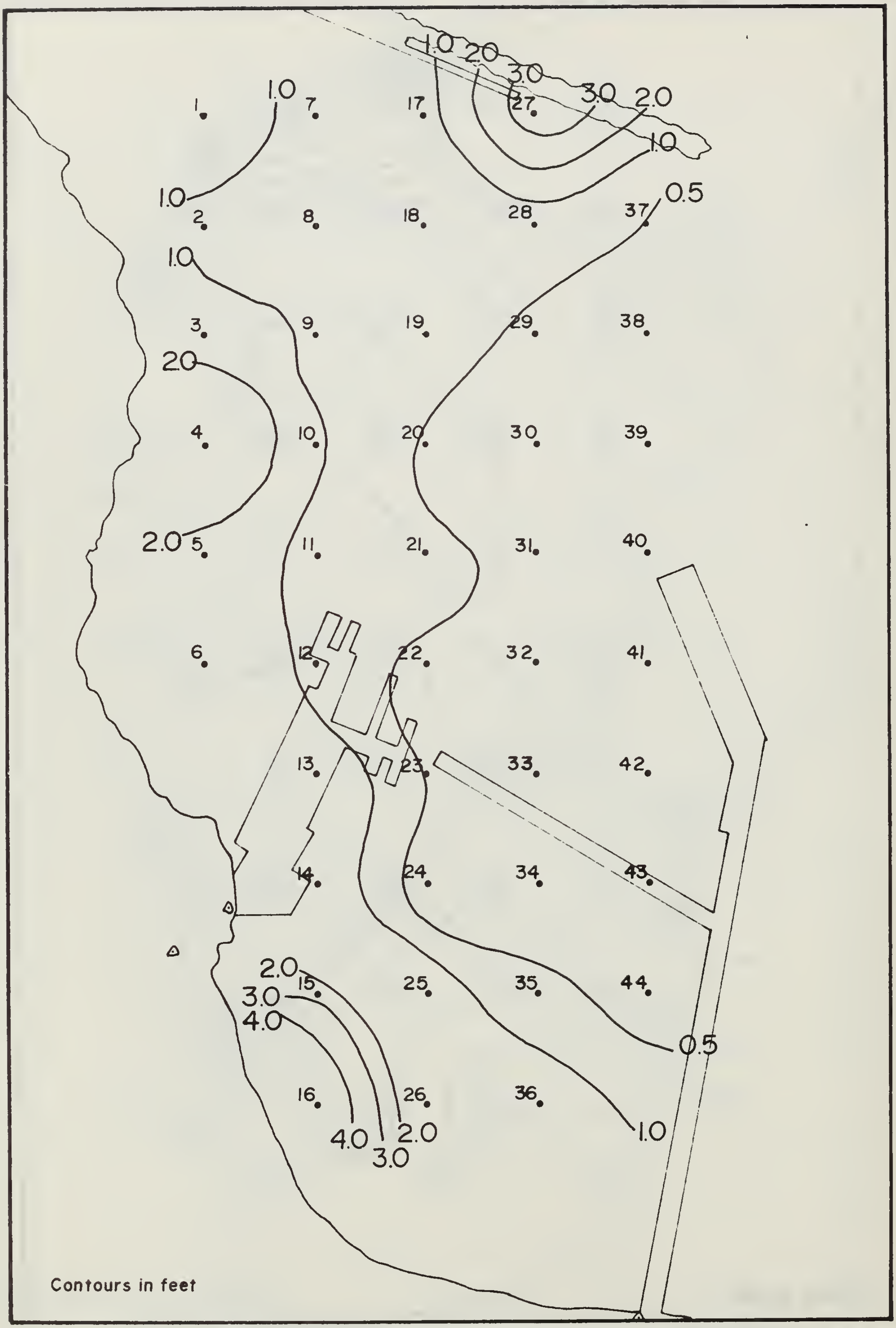


Figure II. Standard Deviation of Depth 1947-1969

The final part examines the plotted contours of the standard deviations covering both periods.

a. Bottom Trends Between 1932-1969

Figure 8 shows the contours of the mean bottom change over the period 1932-1969. The mean rate of change of the bottom is expressed in feet per decade. The harbor bottom shows a long-term trend of shoaling everywhere except for two small areas, one near the outer tip of the Coast Guard Breakwater and the other near the outer end of Wharf 2. In examining Figure 8, the four general areas of activity within the harbor which were revealed by the contoured change charts described above may be recognized. Specifically, these are the shallow-water zone between Wharf 1 and Wharf 2, the area along the rocky coastline, the area adjacent to the Coast Guard Breakwater, and the outer harbor. In the marina beach area shoaling has occurred at a rate of 0.7 foot or greater per decade, giving a mean volume rate of increase per decade of approximately 2,000 cubic feet or greater per 50-foot grid square. When this is multiplied by the number of 50-foot grid squares in the beach area this becomes a significant bottom trend. Likewise, the trend in the northern corner of the harbor and along the majority of the rocky coast line is 0.8 foot or greater per decade over a larger area. Thus, the overall rate of volume increase in this area is also significant. The area of little bottom activity in the central outer harbor is seen to be shoaling at a rate of 0.2 foot or less per decade, and is an unexpectedly stable area.

b. Bottom Trends Between 1947-1969

Figure 9 shows the contours of the mean bottom change over the period 1947 to 1969. Examination of the figure shows a large area of erosion in the shallow-water zone between Wharves 1 and 2 with a trend of

-1.2 foot per decade. There is also a second area of erosion located in the northwestern corner of the harbor on the rocky coast which has a rate of -0.8 foot per decade. Areas of significant shoaling are the nearshore zone along the rocky coast just to the west of Wharf 1, the lee of the outer portion of the Coast Guard Breakwater, and a strip extending from the latter area across the harbor to Wharf 1. In the outer harbor accretion occurred at a slow rate, although around the outer end of Wharf 2 somewhat more rapid filling may be noted.

The long-term bottom-change trends shown in Figure 8 and Figure 9 are seen to be quite different upon comparison. Where Figure 8 shows general accretion, Figure 9 shows some areas of significant erosion. In both, however, the two areas of most active change are the beach and nearshore zone between the two wharves and the rocky coast in the vicinity of the rubble sand trap. Secondarily active areas are the area off the rocky shoreline in the vicinity of the breakwater and inside of the end of the breakwater. The stable outer harbor area experienced slow accretion during both periods.

c. Standard Deviation of the Depth

Figures 10 and 11 show the standard deviation of the depth from the long-term depth trends throughout the harbor for the periods 1932-1969 and 1947-1969, respectively. Both figures show that the variability of the bottom is large in the nearshore area, particularly off the sand beach between Wharf 1 and Wharf 2, and also near the outer end of the breakwater. This is indicative of active shifting of sediments in these areas over the period of the surveys. Very little variability in depth with time is noted in the offshore area beyond the 14-foot contour in the beach area and the 18-foot contour off the rocky coastline, which indicates a stable bottom.

When Figures 10 and 11 are compared the two patterns of bottom depth variation are very similar, although the magnitude of the 1947-1969 deviations were smaller. A comparison of the deviation maps with the depth-trend maps reveals that, in general, areas of most rapid long-term accretion or erosion are also areas of the largest depth deviation from the long-term trend.

In the areas of stable bottom in the outer harbor the standard deviation varied from 0.5 to 0.25 foot, indicating that the accuracy of the series of surveys conducted was very good.

3. Volume-Change Computations

The change in sediment volume in the harbor occurring between successive surveys, and between selected surveys, was computed and the results are tabulated in Table IV. Because these volume changes occurred over variable survey intervals, the volume changes were converted into annual rates of net shoaling or erosion so that the volume changes can be compared on the same rate basis. The volume change between two surveys represents an areal integration of the depth changes between the surveys, and provides an overall indication of the change in the harbor.

The 15 surveys do not cover exactly the same area; accordingly, in order to derive volume figures that can be compared, the area was reduced to the largest area common to all surveys. This area is shown in Figure 6. Unfortunately this resulted in eliminating some of the shoreline zone where large volume changes occurred.

It may be noted in the table that the rates have been highly variable and that both accretion and erosion have occurred between surveys. The largest rate, which was registered over the 3-month period between Survey 3 and Survey 4 (Jul 35 - Oct 35), exceeded 500,000 cubic yards per year.

The actual volume changes between surveys are plotted in Figure 12 in the form of a cumulative volume change with time. This figure shows that: (1) A discontinuity in the trend of the net volume change occurred about 1945; the mean volume change from 1932-1945 was much larger than from 1945-1969. (2) Overall shoaling rates averaged 17,500 cubic yards per year from 1932-1969 and 7,100 cubic yards per year from 1947-1969.

The volume analysis was not carried further, but there are other promising ways of handling these data. One suggestion for further analysis would be to examine the volume changes by grid squares in order to determine changes on a smaller scale or in limited parts of the harbor. Also, the positive and negative volume changes between two surveys could be calculated separately.

TABLE IV

VOLUME FIGURES FOR COMMON AREA

This table shows the amount of change in volume experienced between surveys and the annual rate derived therefrom. The area of the harbor common to all surveys is shown by the heavy dashed line in Figure 6, and totals 274,186 sq yards. Positive values of change represent net accretion between surveys and negative values represent erosion.

Surveys Compared	Comparison Number	Volume Change Between Surveys (cu yds)	Number of Months	Annual Rate of Change (cu yds/yr)
1-2	1	149,262	19	94,271
2-3	2	21,242	16	15,931
3-4	3	-132,925	3	-531,699
4-5	4	17,393	23	9,075
5-6	5	216,405	10	259,686
6-7	6	458,113	88	62,470
7-8	7	-233,416	14	-200,070
8-9	8	5,873	11	6,406
9-10	9	20,019	16	15,015
10-11	10	76,326	27	33,923
11-12	11	-121,193	6	-242,387
12-13	12	159,713	29	66,088
13-14	13	-83,398	108	-9,266
14-15	14	99,704	65	18,407
1-15	15	649,157	436	17,545
8-15	16	157,038	264	7,138

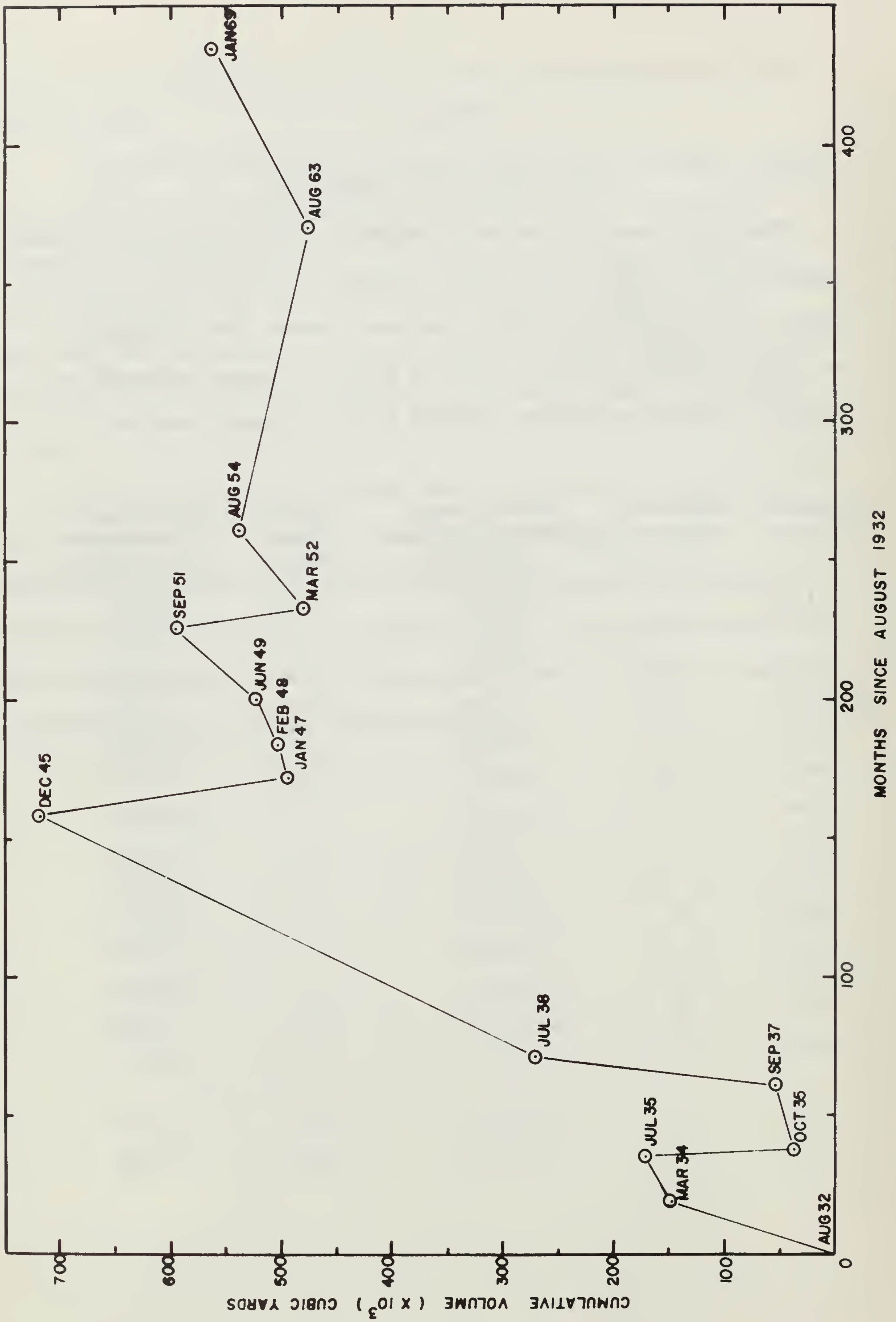


Figure 12. Cumulative Volume vs Time

B. SEDIMENT REGIME AND THE EFFECT OF HARBOR WORKS

The purpose of this section is to present deductions regarding the sediment regime in the harbor based on the observations presented earlier, and to inquire into the effects of structures and dredging on sedimentation in the harbor.

1. Sediment Regime

No attempt has been made to establish a sand budget for the harbor, and the following discussion of the sediment regime therefore represents a series of deductions based upon all available information.

The areas of active bottom change in the harbor have been shown to be the beach and nearshore zones, and the bottom adjacent to the breakwater. These are also the areas of sand bottom. The undisturbed appearance of the mud bottom in the outer harbor indicates that sand does not move across it. Accordingly, it may be deduced that sand movements are restricted to the nearshore zone and the bottom close to the breakwater.

Bottom changes between surveys in these areas can be attributed only to a net gain or loss of sand in the harbor due to exchange with the adjacent beaches, or to local redistribution of sand within the harbor. A net gain or loss may be brought about by littoral drift exchange with Del Monte Beach on the upcoast side of the harbor or by transport around the end of the breakwater by wave currents generated along the seaward face of the breakwater or possibly by tidal currents. Evidence that the latter occurs is given by the location and shape of the sediment accumulation on the inside of the outer end of the breakwater. Examples of this accumulation may be noted in Comparisons 14, 15, and 16, and also by the trend toward shoaling in this area as shown in Figure 9.

Additionally, an increase in depth noted directly off the end of the breakwater is indicative of a scoured area as would be caused by currents moving around the breakwater. It appears improbable, however, that significant transport of sand out of the harbor around the breakwater occurs due to the lack of apparent generating forces in the harbor to produce currents of sufficient strength moving out of the harbor area. With regard to redistribution of sand within the harbor, no clear-cut pattern occurs except in the area between Wharf 1 and Wharf 2 where the beach clearly has experienced general onshore-offshore migration of sand between the shallow-water zone and the beach. However, the changing zones of cut and fill noted off the rocky shoreline suggest that the topography of these zones may be a controlling factor in the manner in which the sediments are redistributed.

It is evident that if sand exchange between the harbor and the adjacent coast is significant, a large net change in the sediment volume of the harbor should be indicated from one survey to another, whereas if the exchange with adjacent beaches is small the net volume change should also be small even though large bottom changes may occur within the harbor. Unfortunately, the fact that the study area does not include the beach backshore means that sand could be redistributed internally within the harbor with no exchange taking place with adjacent areas and still a significant volume change may be registered for the harbor in Table IV.

It is probable that the large volume changes listed in Table IV that occurred prior to construction of the east wall along Wharf 2 are due largely to sand exchange with Del Monte Beach by littoral drift. Upcoast littoral drift, indicated by large negative volumes representing a net loss of sand from the harbor, is probably caused mainly by a dominance of northwesterly swell which arrive with small upcoast angles of wave incidence. Large positive volumes representing net accretion are probably caused by the occurrence of Bay Wind Storms and by a predominance of long-period southerly swell. Some of the volume change recorded in the figures of Table IV may be due to dredging operations in which sand has ordinarily been dredged from the seaward part of the beach deposit and placed on the beach proper outside the area of the hydrographic surveys. This situation would give an erroneous indication of a net loss of sand from the harbor.

Construction of the bulkhead on Wharf 2 in 1960 cut off the sand exchange with Del Monte Beach, but in spite of this barrier the harbor gained sediment at an approximate annual rate of 18,000 cubic yards over the seven-year period between Surveys 14 and 15. It thus appears that sand flow around the breakwater must account for the bulk of this net accretion. Additional study of the sediment budget for the harbor would be required to test this deduction.

The slow net gain of fine sand and silt that has occurred in the outer harbor over the period of study may be attributed in part to heavy discharge of sediment by the Salinas River (Figure 2) during periods of flooding. This investigator observed that immediately following the period of major floods in January and February 1969 approximately a half inch of fine sediment was deposited on the exposed rock bottom off Del Monte Beach within a quarter mile of the harbor.

2. Effect of Harbor Structures

The structures built in Monterey Harbor during the period of the study (Figure 3) appear to have had the following effects on sedimentation.

The Coast Guard Breakwater generally serves to protect the harbor from the north, acts as a trap for any sediments entering the harbor, and induces wave currents in its vicinity. This structure also appears to have caused a slight sand accumulation on the beach on its seaward side.

The east wall prohibits the exchange of sand between the marina and Del Monte Beach. Survey 15 of Appendix A reveals that a small fillet of sand has accumulated against the outside of the wall since it was built nine years ago.

The frontal wall, which is located in the area of stable bottom, has no apparent effect on sedimentation as indicated by the fact that there has been very little accumulation or erosion on either side. This structure contains a tidal-current circulation within the marina, and also protects the beach area between the two wharves from the full force of incident waves.

The Rubble Sand Trap has been virtually useless over the years and is presently considered an eyesore by the City of Monterey. Steps are being taken for its removal.

The Sea Wall and Small Boat Launching Ramp both reduce the movement of sand from the beach area into the southernmost corner of the marina. These structures have replaced the beach in this portion of the marina, thereby eliminating a source of sediment for onshore-offshore exchange.

The two storm drains contribute limited quantities of sediment to the marina area. Indications were noted in various survey comparisons that the large drain located under Wharf 2 is the major source of sediments so derived.

3. Effect of Dredging Operations

The major dredging operations are listed in Table I. Generally the effects of dredging have only been of a local nature and have had a limited period of effectiveness. For example, the dredging operation between Wharf 1 and Wharf 2 carried out in 1947 by the Corps of Engineers removed approximately 58,000 cubic yards of sand, of which about 38,000 cubic yards of the spoil was placed on the beach between the two wharves as fill for depleted areas. The Corps of Engineers (1959) estimated that within the 2½ year period following the dredging over 21,000 cubic yards of beach material had been redistributed back to the area of dredging.

The spoil from dredging operations both offshore and in the shallow-water zone (Figure 3) has been placed within the harbor area in apparently every instance, and has been redistributed locally by natural causes. It thus appears that the procedure of retaining the dredge spoil within the harbor area has been in error.

IV. RECOMMENDATIONS

The following recommendations are made in light of this study.

A. SURVEY TECHNIQUES

Survey techniques in which some improvements are desirable are:

1. All surveys for a particular area should be plotted using the same scale. There should be common grid lines to aid in relating one survey to the next for purposes of computer comparison.

2. The scale most desirable is 1" = 50' for nearshore and harbor surveys. When scales in excess of 1" = 100' are used, too much smoothing of the bottom contours is required and some detail is lost.

3. When surveying an area such as Monterey Harbor, beach portions of the shoreline should be resurveyed each time in order to obtain a record of the shoreline location for survey comparison purposes.

4. Monterey Harbor and other coastal harbors should be surveyed on an annual basis to provide better control of information on the changes occurring.

B. FURTHER STUDIES

The following subjects are recommended for further study to better understand the changing nature of Monterey Harbor.

1. A sediment budget for the harbor should be determined.

2. A geological study should be made in the harbor area of the thickness of sediments overlying the bedrock and the location of the contact between the Santa Lucia and Monterey Formations.

3. Computer processing of the hydrographic data in limited areas of the harbor, such as the beach area between Wharves 1 and 2, in order to examine local conditions would provide additional information concerning bottom changes.

BIBLIOGRAPHY

1. Breidenstein, J. F., and D. M. Thomas, 1965. A Study of Water Circulation in Monterey Harbor Using Rhodamine B Dye. Naval Postgraduate School, MS Thesis.

2. Bixby, H. L., Jr., 1962. Storms Causing Harbor and Shoreline Damage Through Wind and Waves Near Monterey, California. Naval Postgraduate School, MS Thesis.

3. Corps of Engineers, U. S. Army, 1959. Survey Report on Monterey Bay, California. 86th Congress, 1st Session, House Document No. 219, U. S. Government Printing Office, Washington, D. C.

4. Dorman, C. E., 1968. The Southern Monterey Bay Littoral Cell: A Preliminary Sediment Budget Study. Naval Postgraduate School, MS Thesis.

5. Hohenstein, C. G., J. W. Jaeger, and D. L. Jones, 1965. A Study of Marked Sand Movement on Del Monte Beach, Monterey, California. Naval Postgraduate School, MS Thesis.

6. National Marine Consultants, 1960. Wave Statistics for Seven Deep-Water Stations Along the California Coast. Prepared for the Los Angeles and San Francisco Districts, U. S. Army, Corps of Engineers.

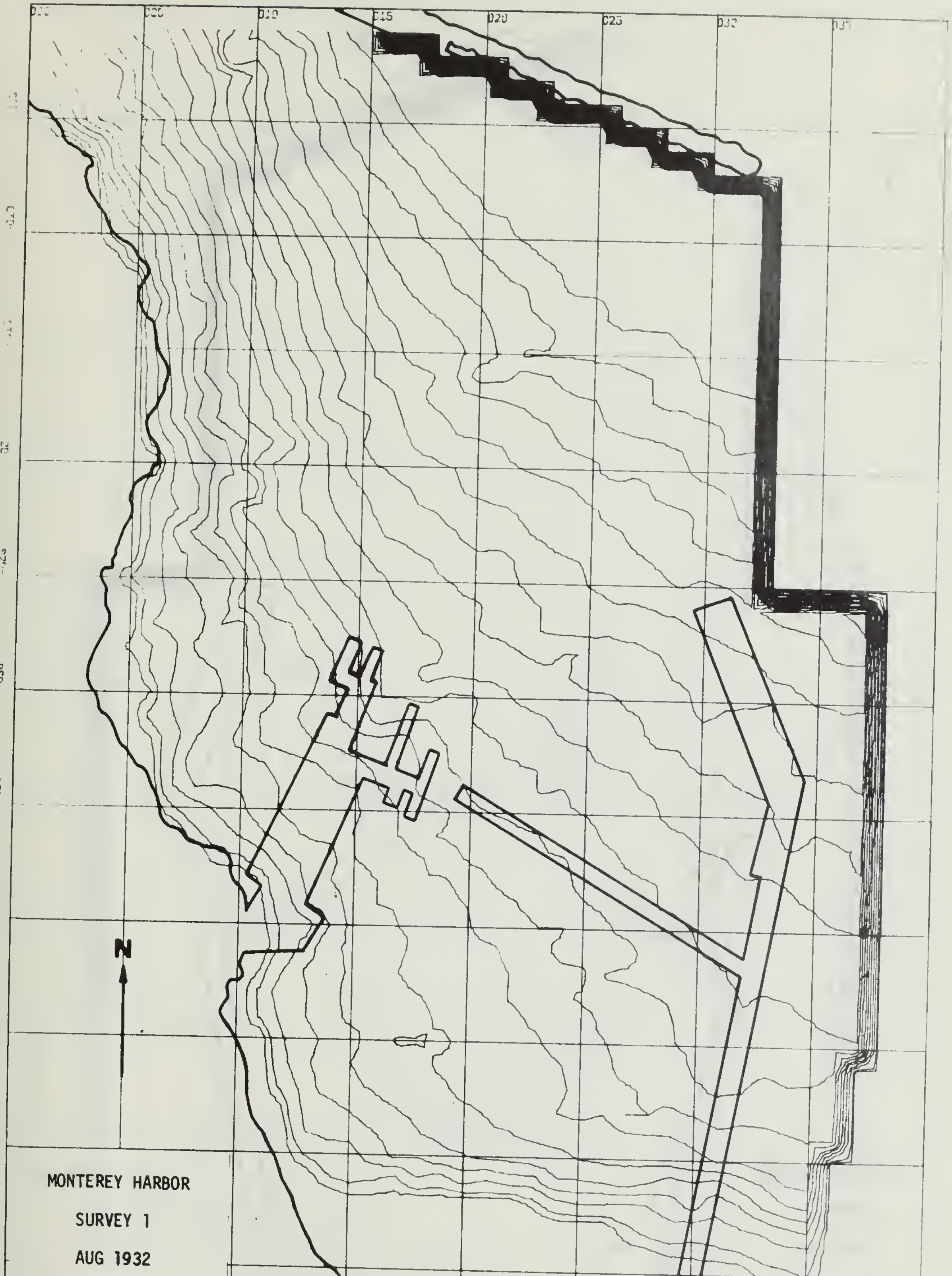
7. Rohrbough, J. D., J. E. Koehr, and W. C. Thompson, 1954. Quasi-weekly and Daily Profile Changes on a Distinctive Sand Beach. Proceedings of Ninth Conference on Coastal Engineering, American Society of Civil Engineers.

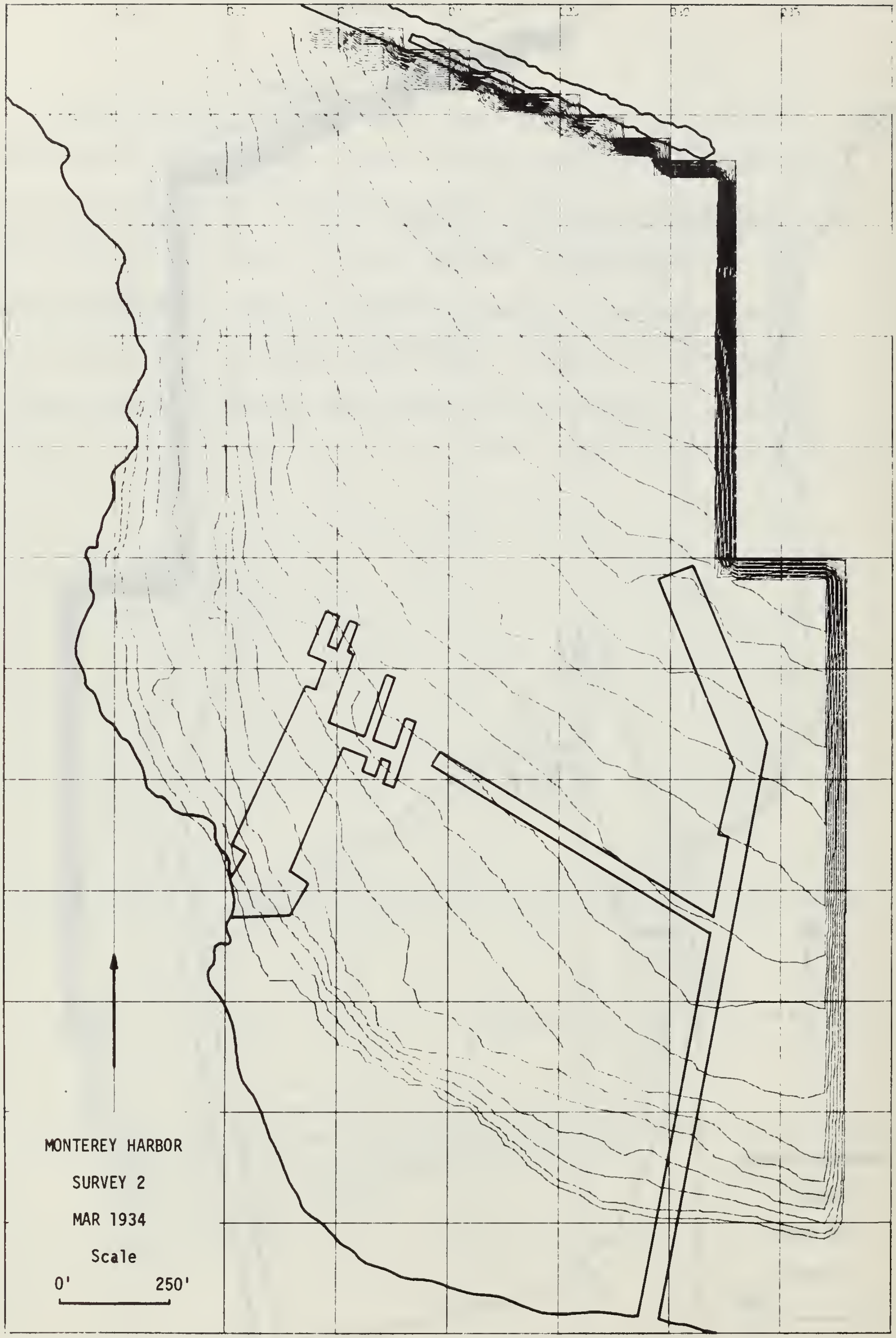
8. Wilson, B. W., J. A. Hendrickson, and R. E. Kilmer, 1965. Feasibility Study for a Surge-Action Model of Monterey Harbor, California. U. S. Army Engineers Waterways Experimental Station, Corps of Engineers, Vicksburg, Mississippi, Contract Report No. 2-136, October.

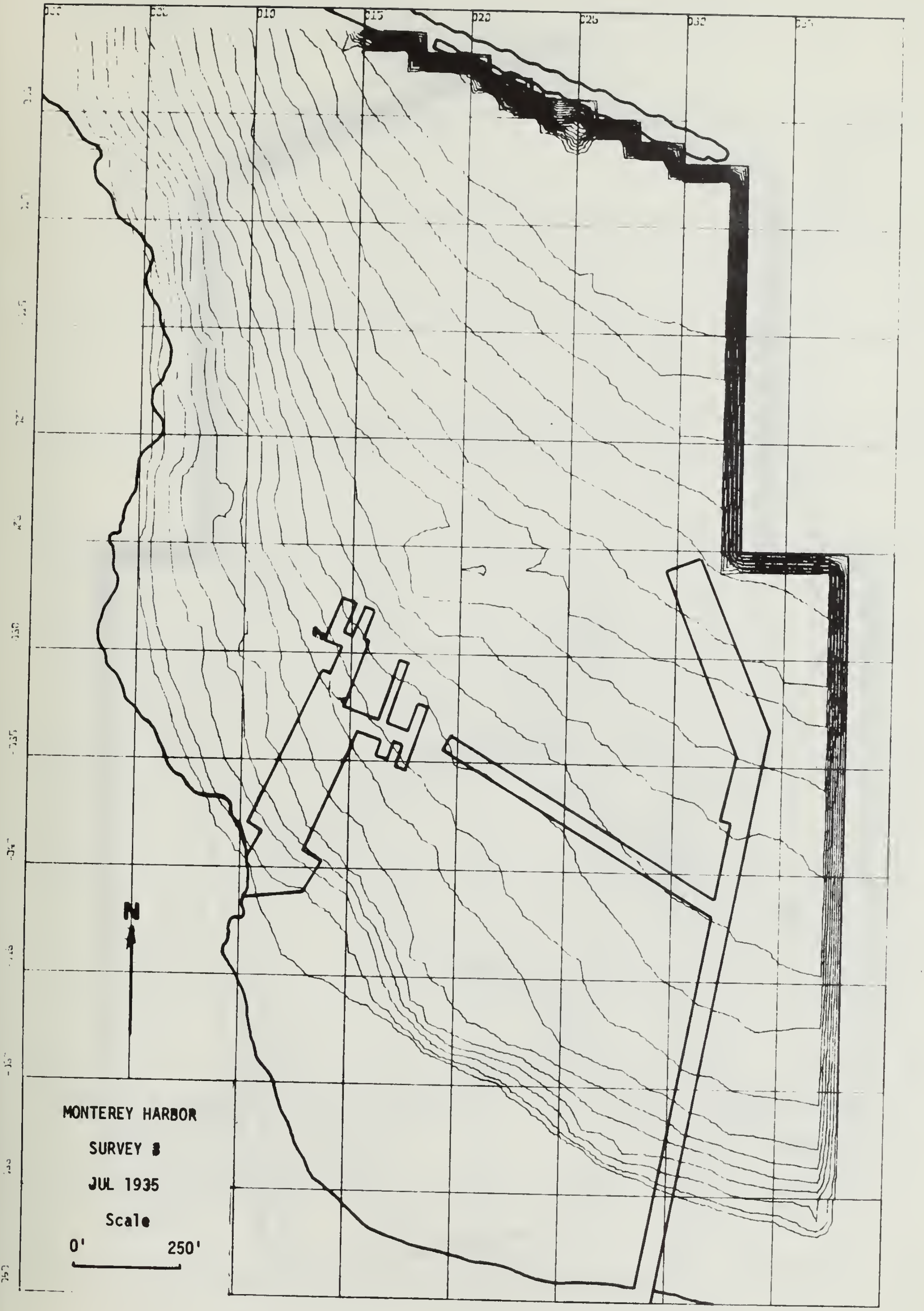
APPENDIX A

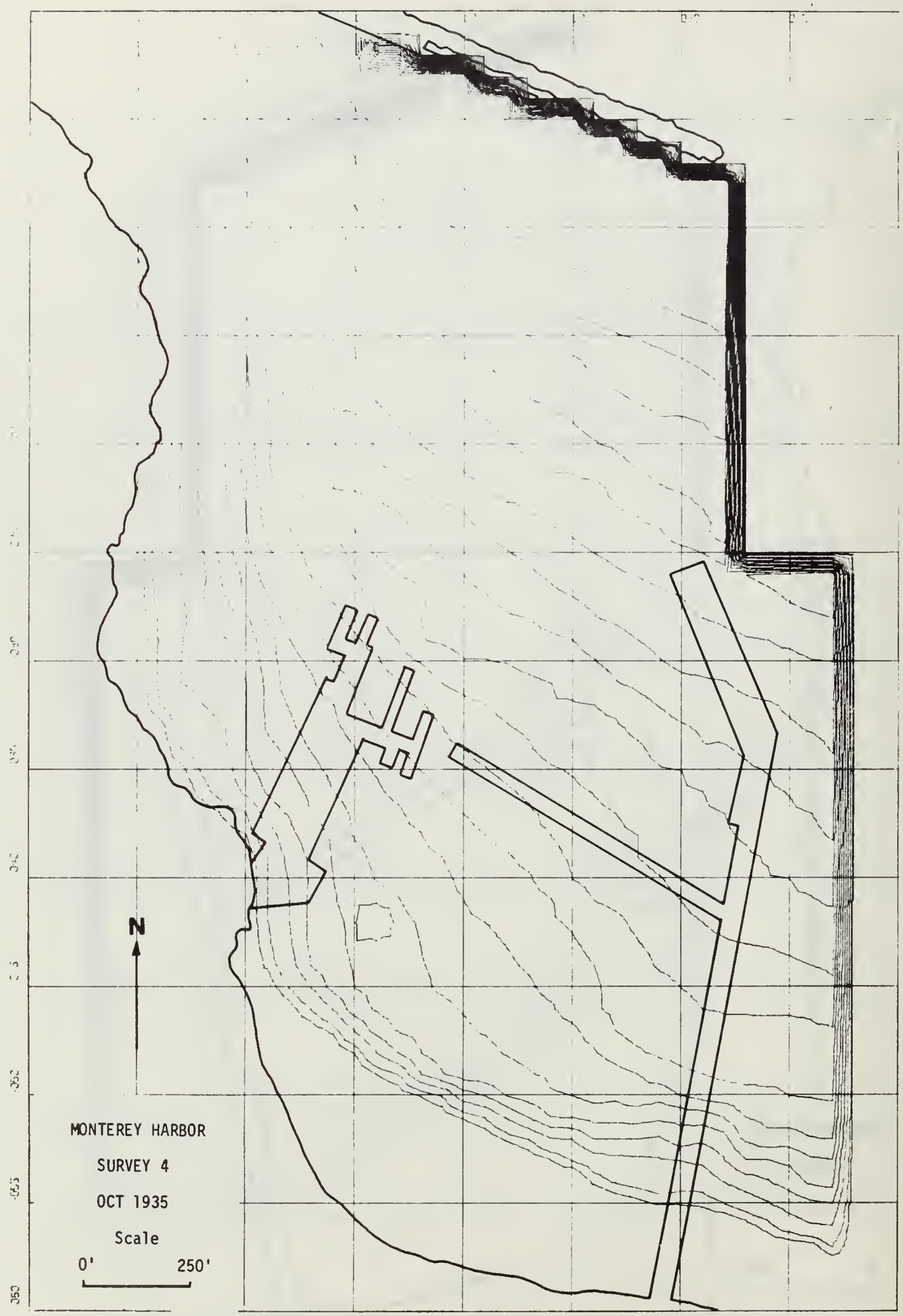
SURVEYS 1 through 15

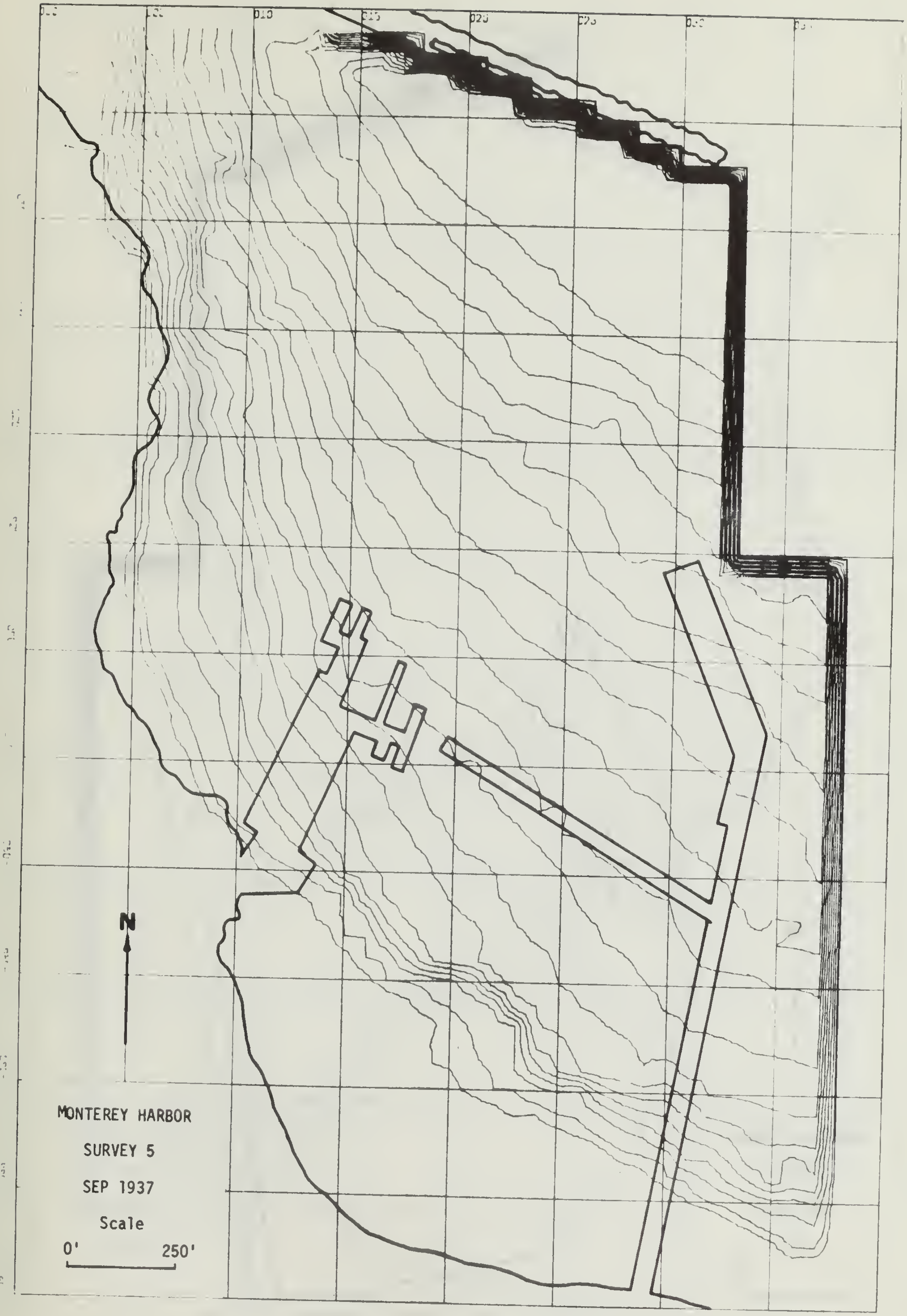
The fifteen hydrographic surveys used for comparison throughout the study are presented. The shoreline on all charts is taken from the 1932 survey. The initial contour adjacent to this shoreline is one foot, followed by a two-foot contour; subsequent contours are at two-foot intervals. The datum is Mean Lower Low Water. The identification and characteristics of the original survey charts are listed in Table II.


010
015
020
025
030
035
-030
-035
MONTEREY HARBOR
SURVEY 1
AUG 1932
Scale
0'
250'
N


MONTEREY HARBOR
SURVEY 2
MAR 1934
Scale
0'
250'


010
015
020
025
030
N
MONTEREY HARBOR
SURVEY 3
JUL 1935
Scale
0'
250'


N
MONTEREY HARBOR
SURVEY 4
OCT 1935
Scale
0'
250'



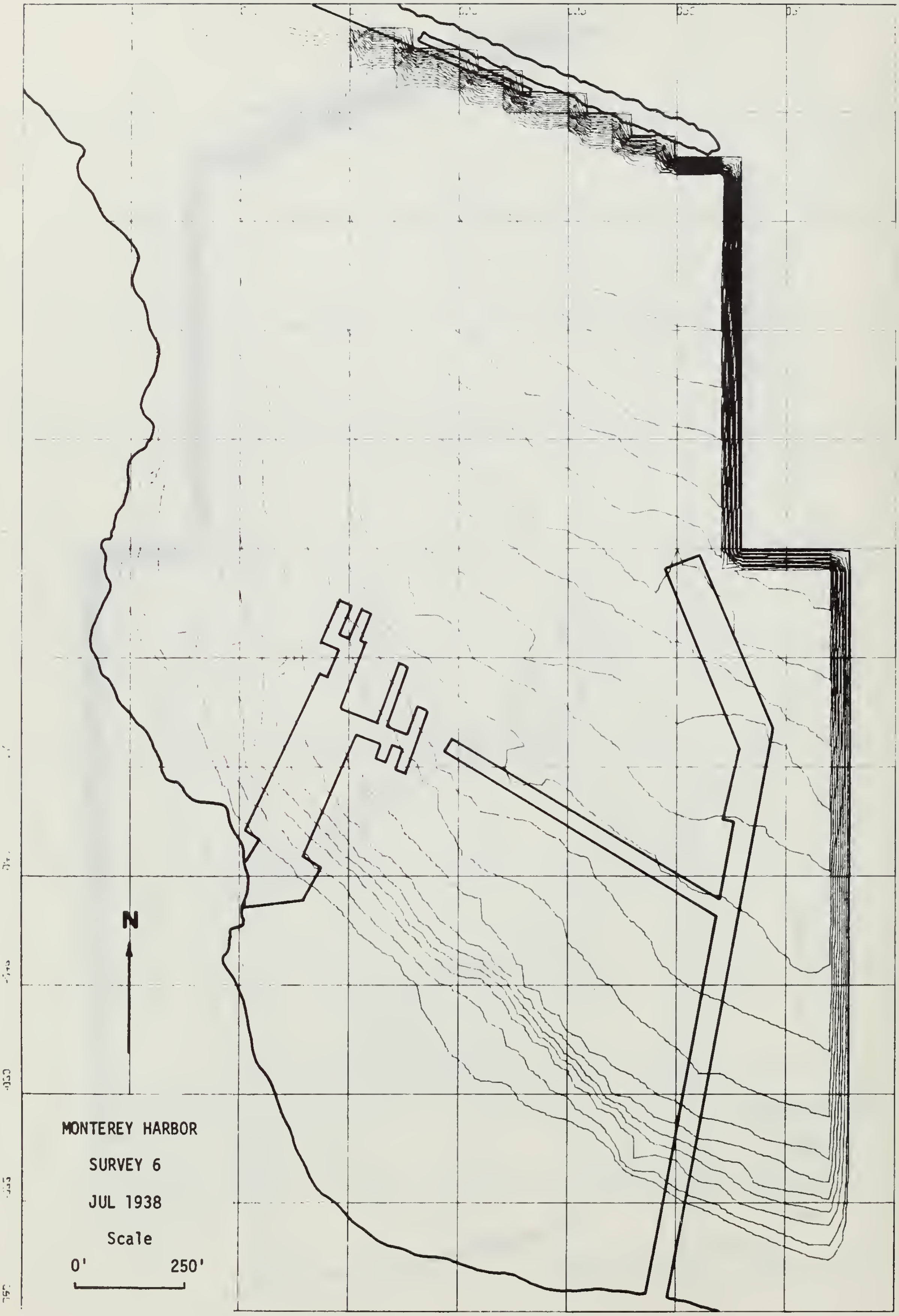
MONTEREY HARBOR

SURVEY 5

SEP 1937

Scale

0' 250'

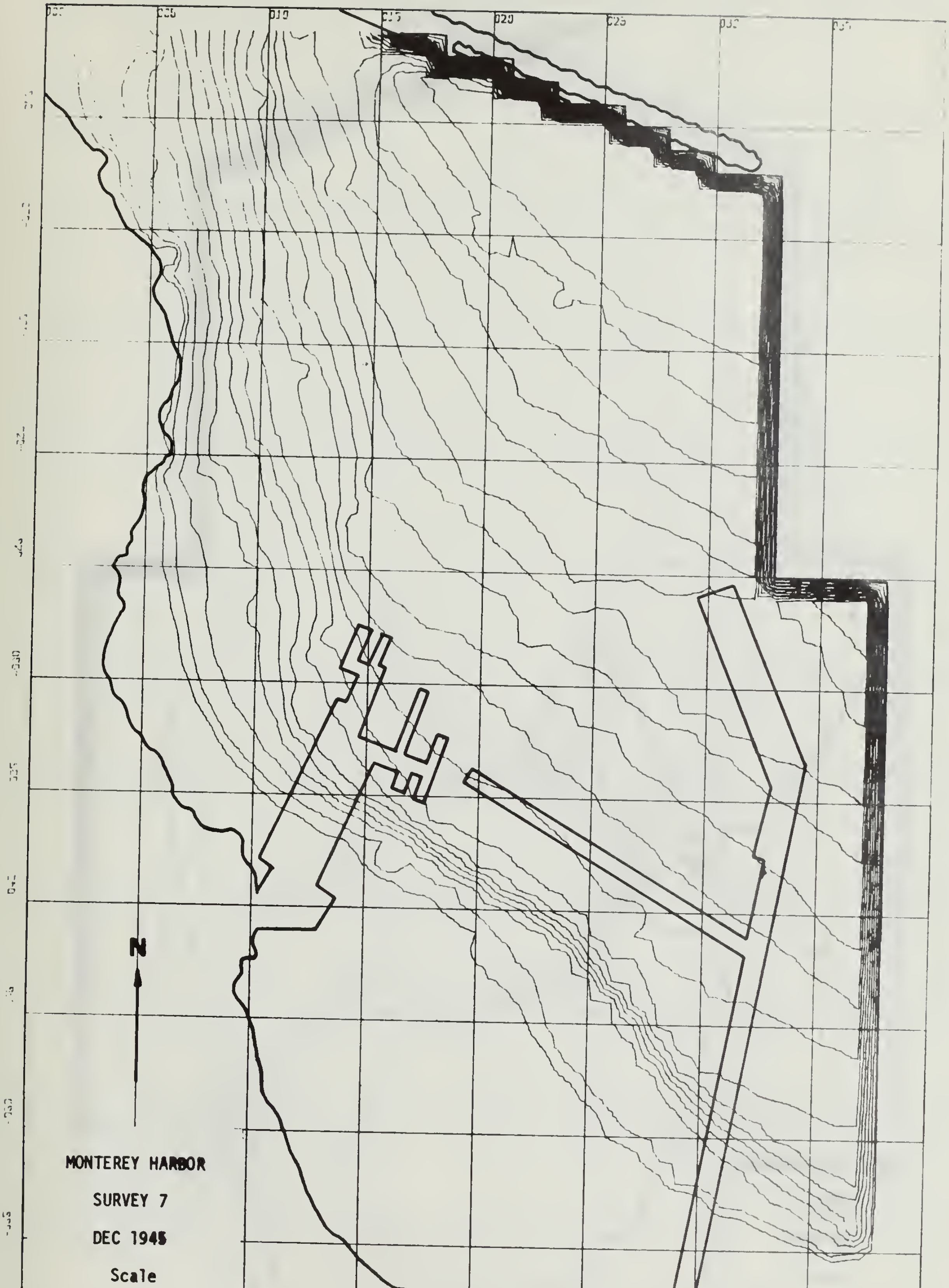


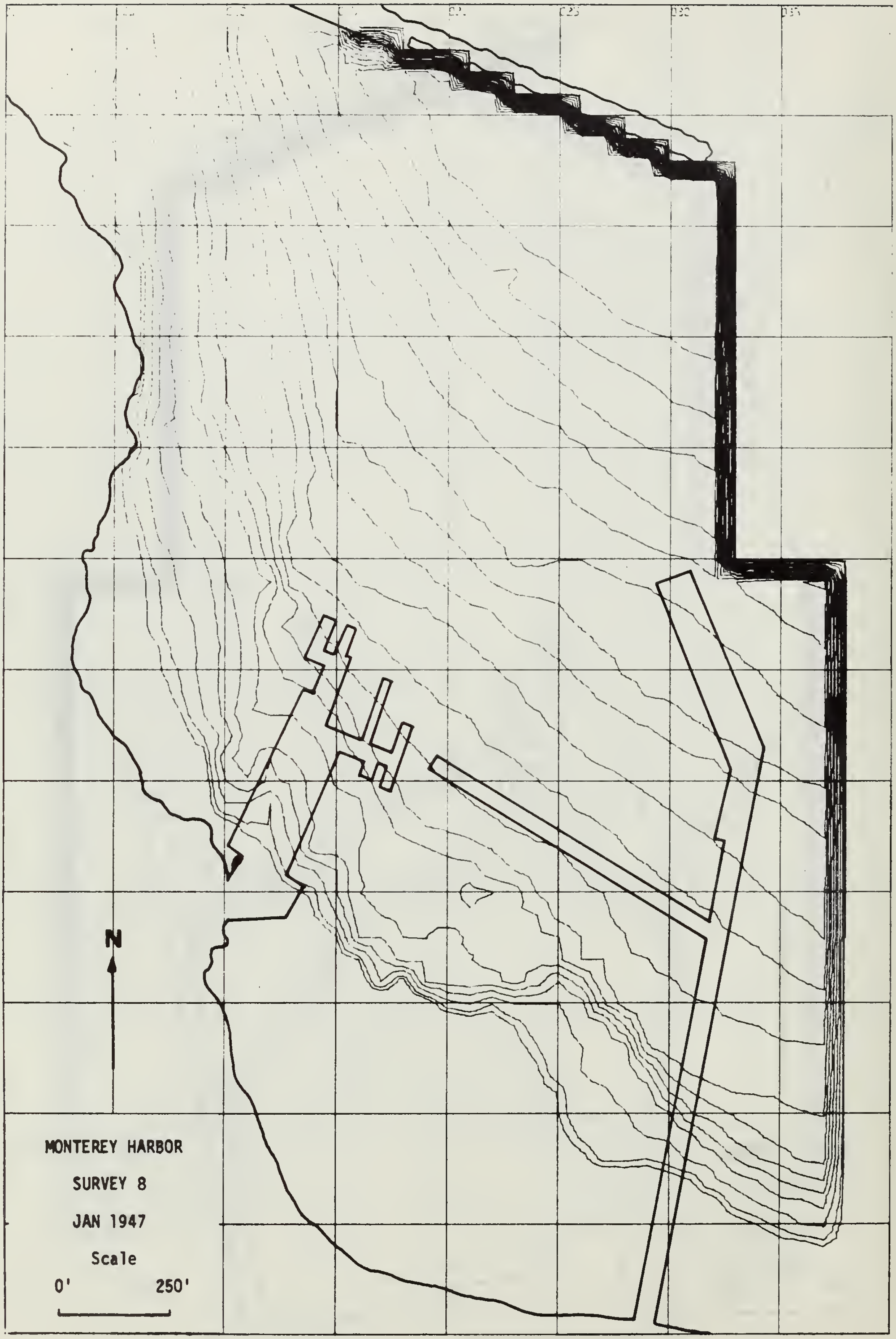
MONTEREY HARBOR

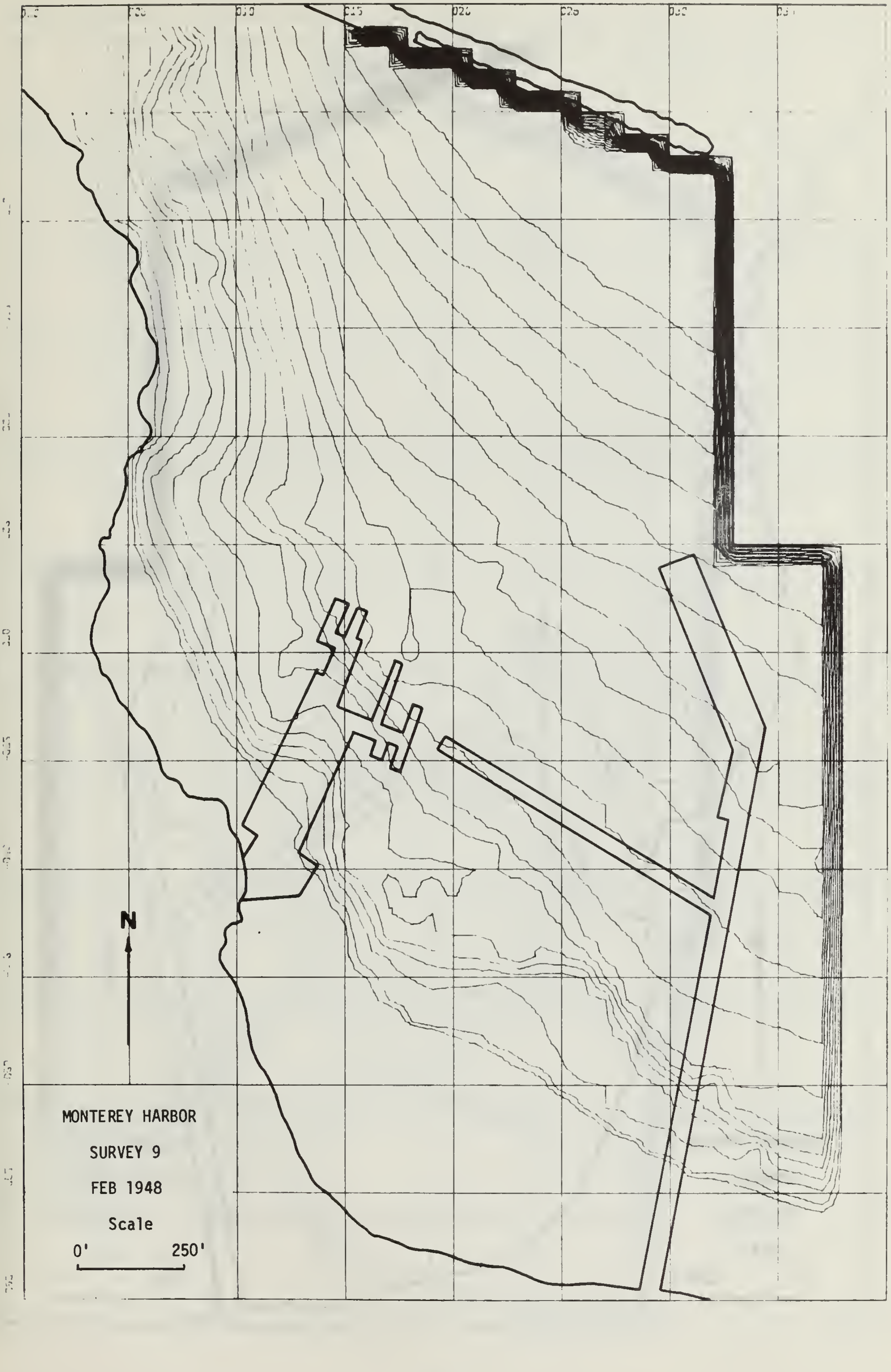
SURVEY 6

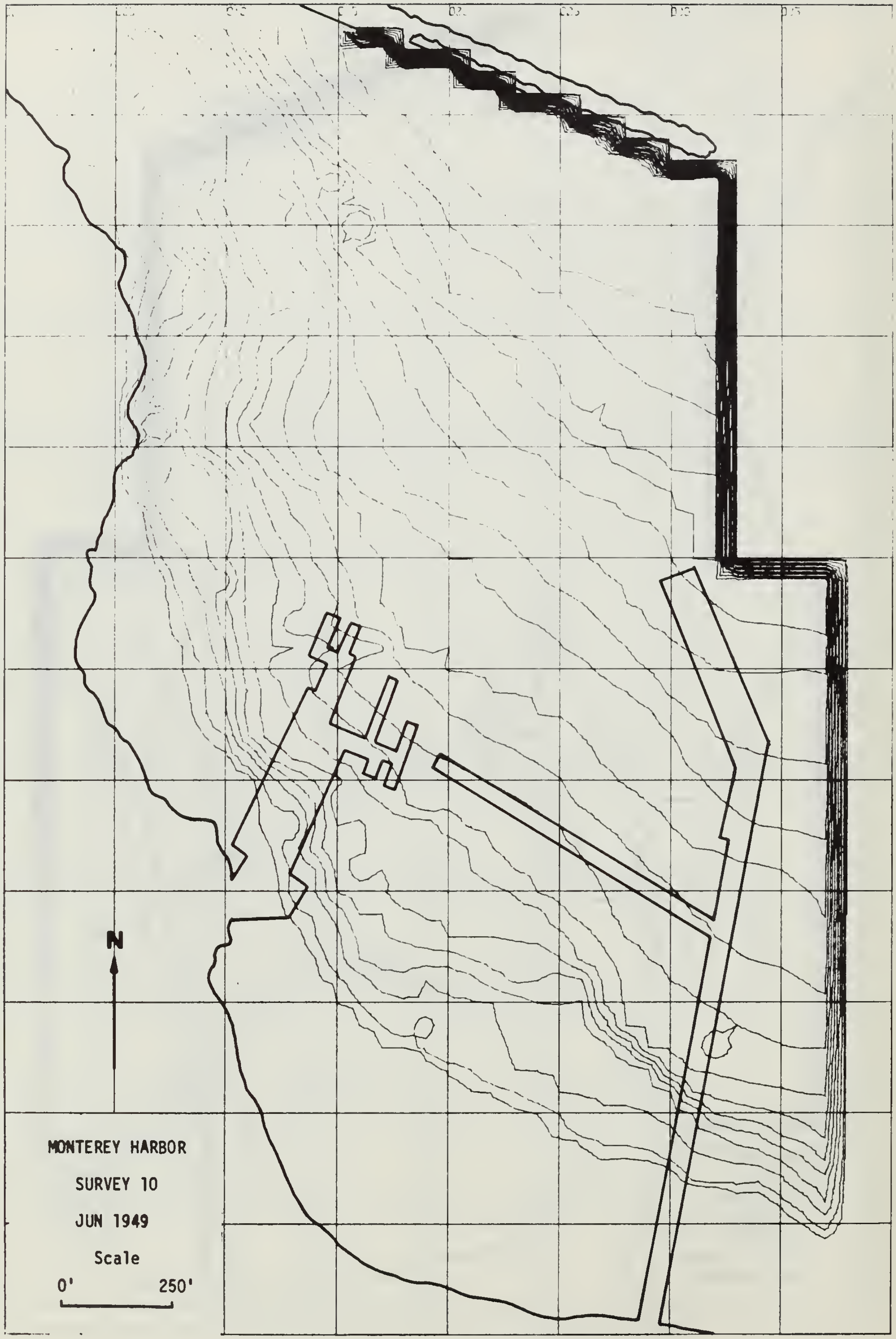
JUL 1938

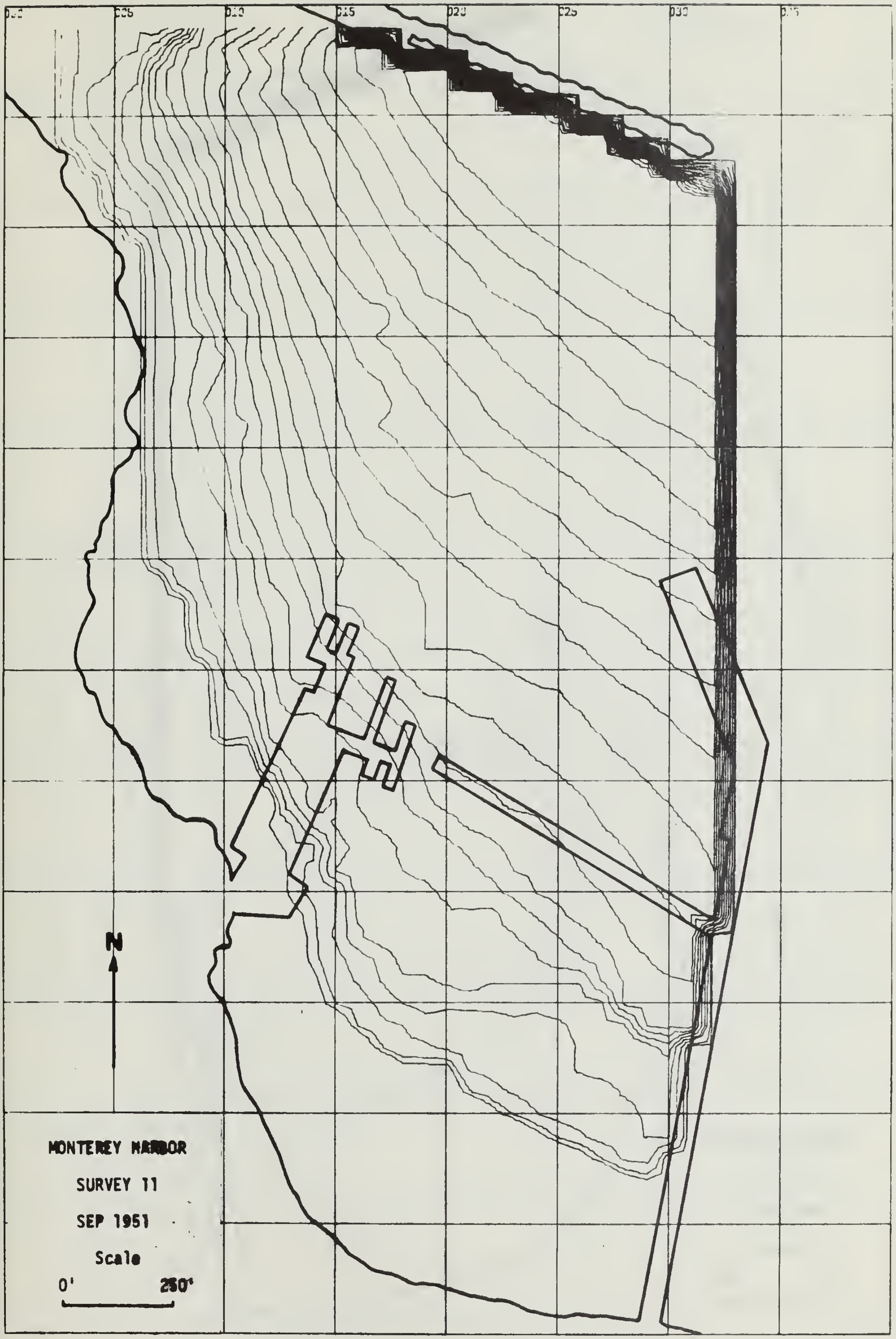
Scale


010
020
025
N
MONTEREY HARBOR
SURVEY 7
DEC 1945
Scale
0'
250'


025
030
035
030
035
040
045
050
055
060
N
MONTEREY HARBOR
SURVEY 8
JAN 1947
Scale
0'
250'


MONTEREY HARBOR
SURVEY 9
FEB 1948
Scale
0'
250'
N


N
MONTEREY HARBOR
SURVEY 10
JUN 1949
Scale
0'
250'



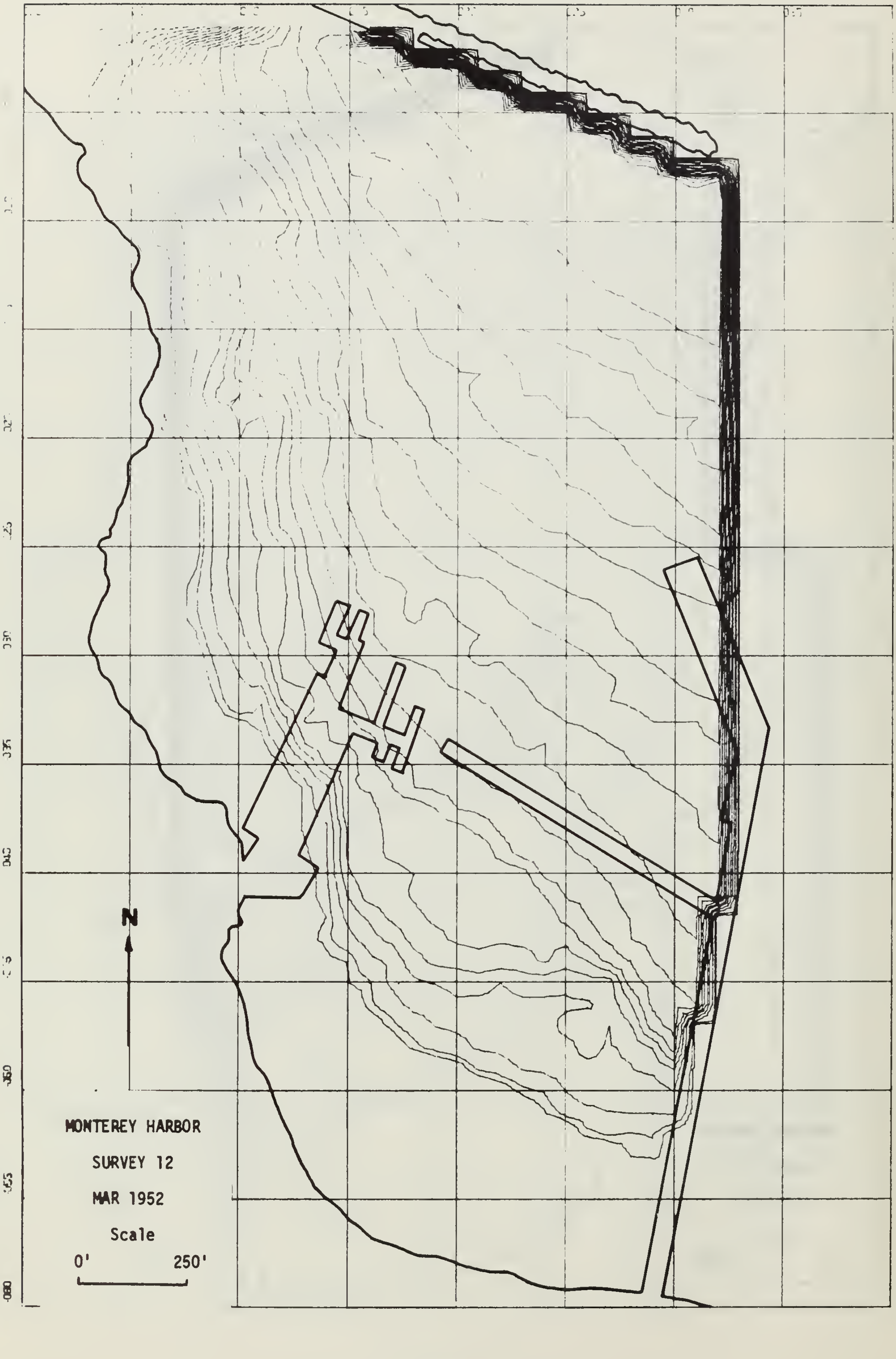
MONTEREY HARBOR

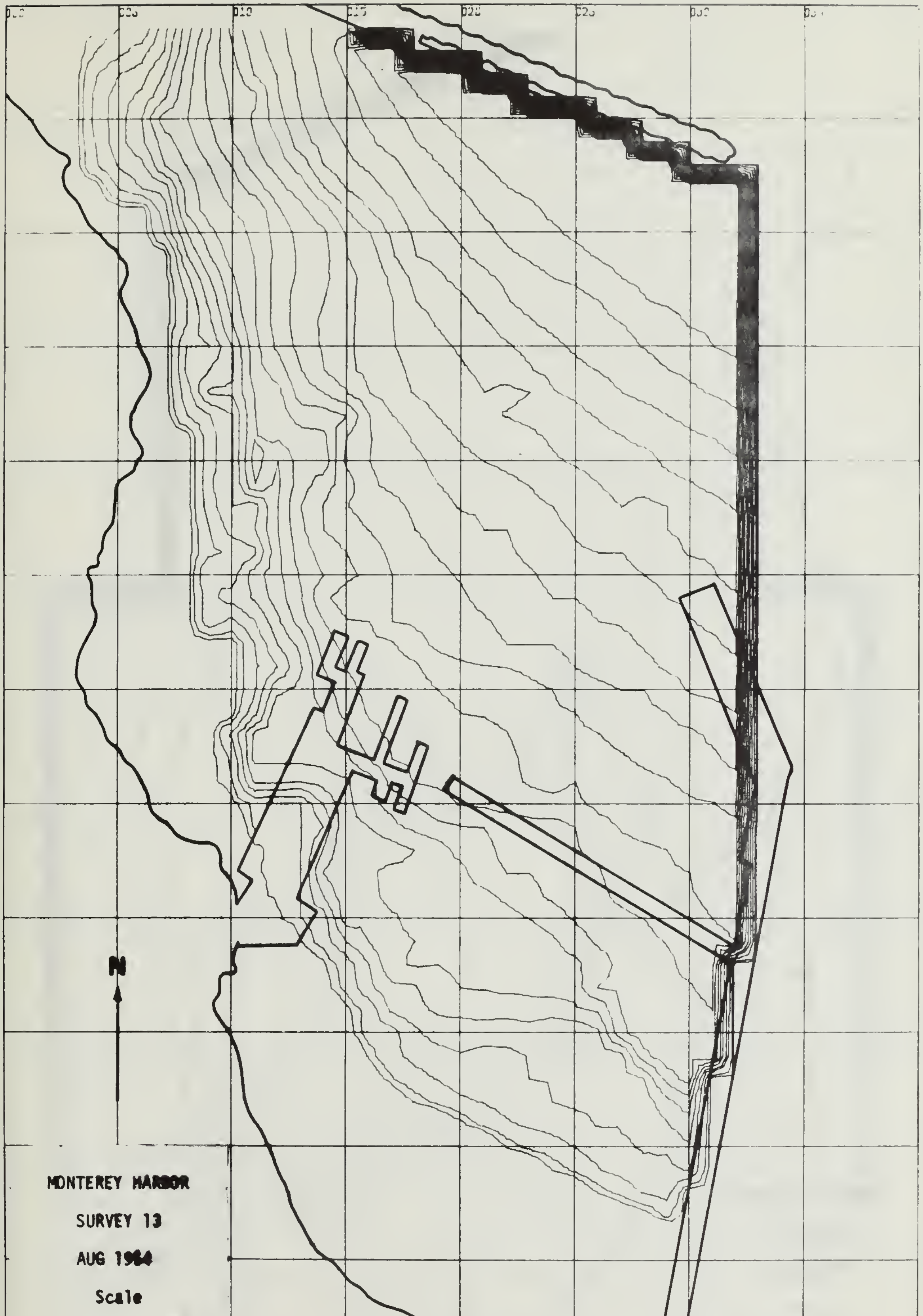
SURVEY 11

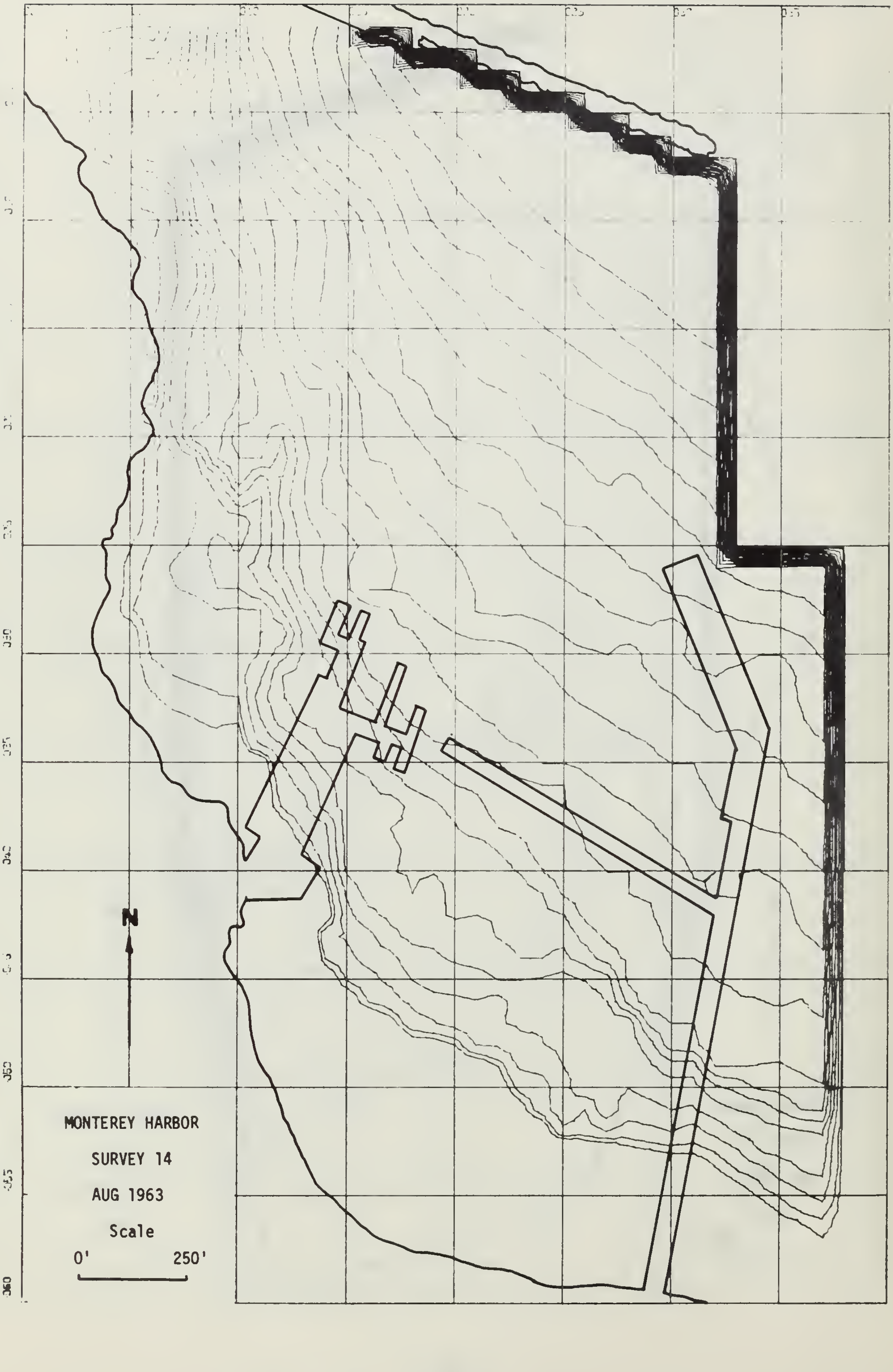
SEP 1951

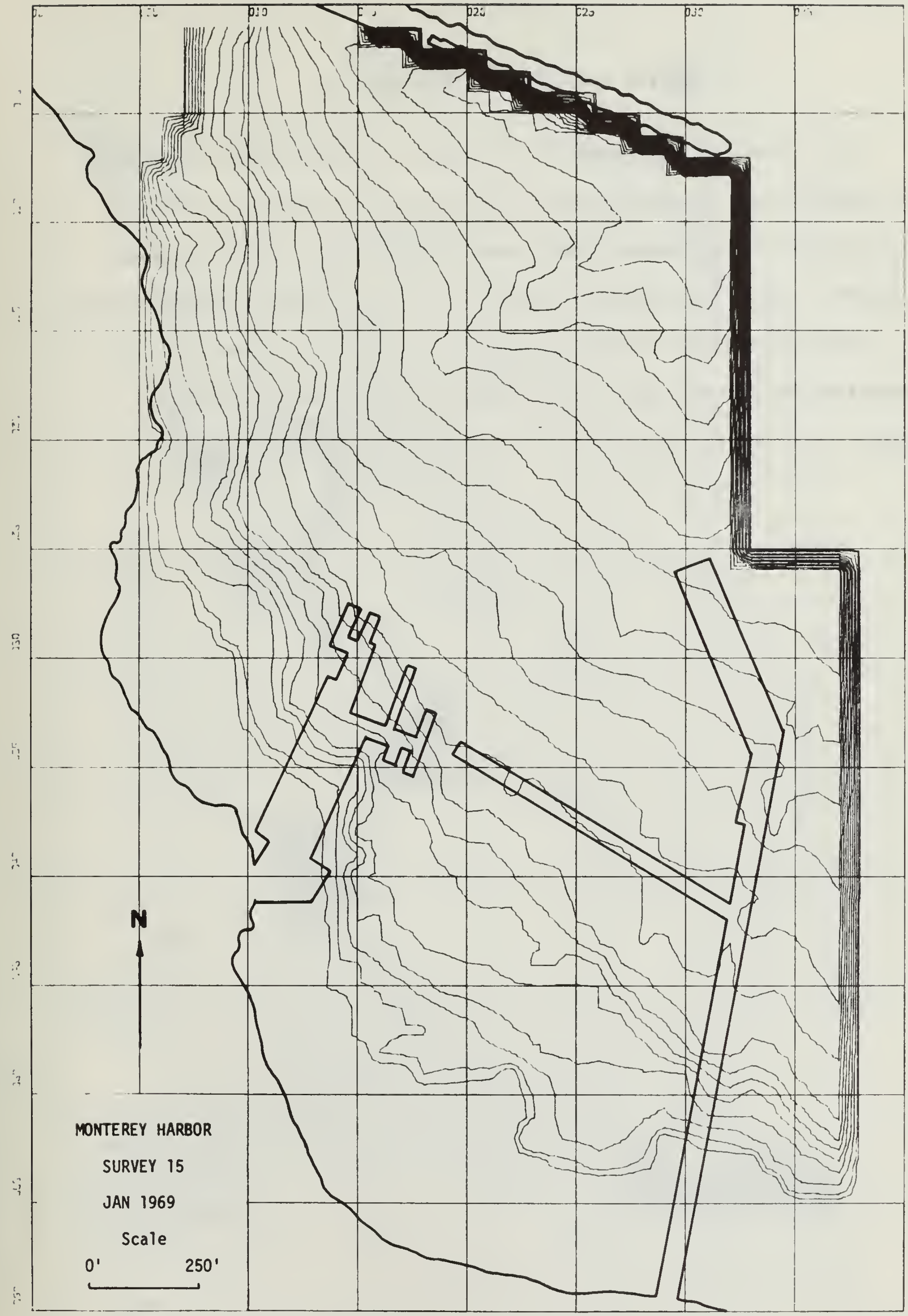
Scale

0' 250'


N
MONTEREY HARBOR
SURVEY 12
MAR 1952
Scale
0'
250'


010
015
020
-030
-035
-050
-055
-060
N
MONTEREY HARBOR
SURVEY 13
AUG 1984
Scale
0'
250'


N
MONTEREY HARBOR
SURVEY 14
AUG 1963
Scale
0'
250'

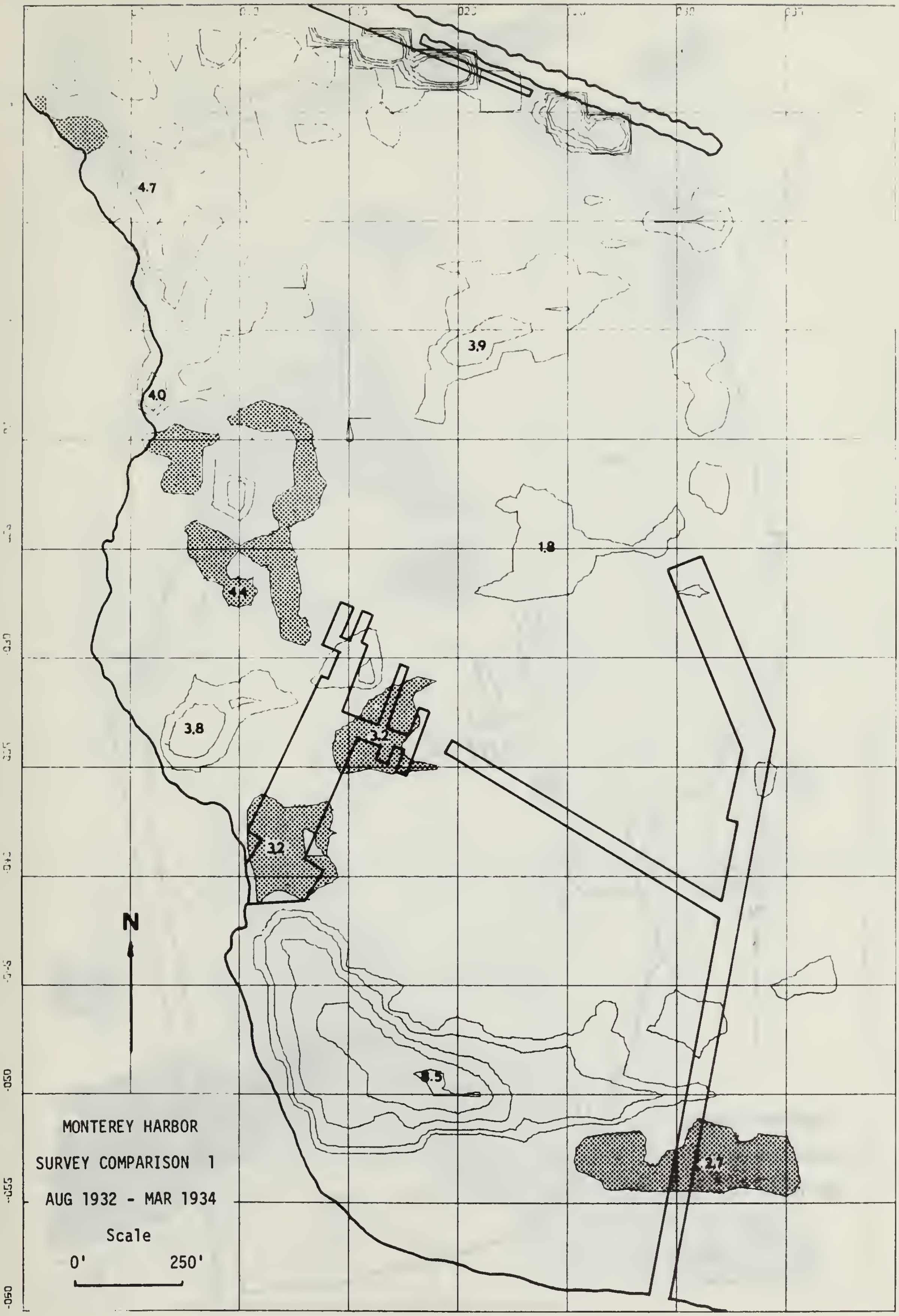

N
MONTEREY HARBOR
SURVEY 15
JAN 1969
Scale
0'
250'

APPENDIX B

SURVEY COMPARISONS 1 through 16

The sixteen survey comparisons listed in Table III are presented. The shaded areas indicate erosion of one foot or greater. The areas of accretion are contoured where they indicate shoaling of one foot or greater, the inner contours being 2, 4, 6, and 8 feet where required.

Also included are illustrations showing the area common to each comparison in relationship to the overall area delineated for the study.



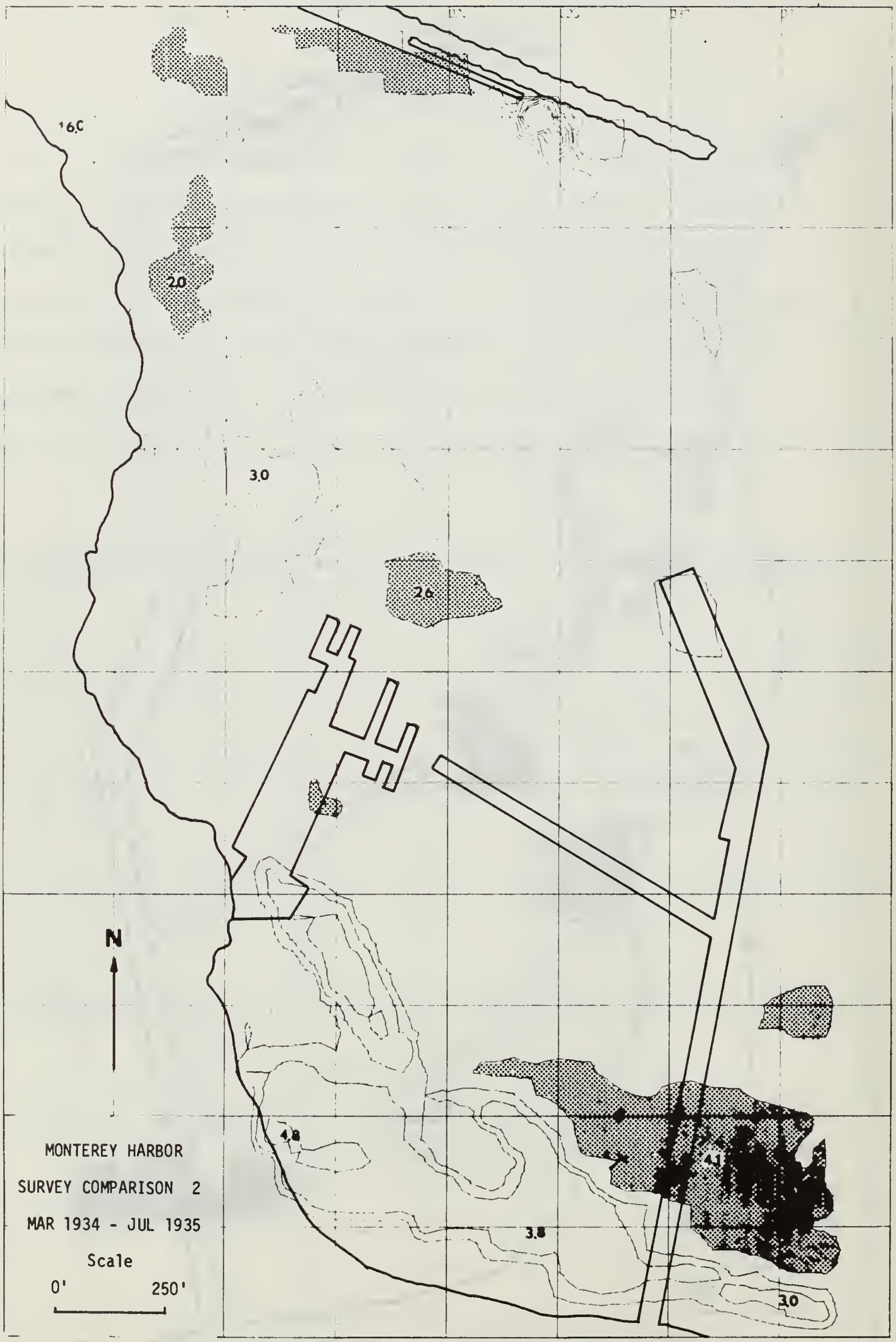
MONTEREY HARBOR

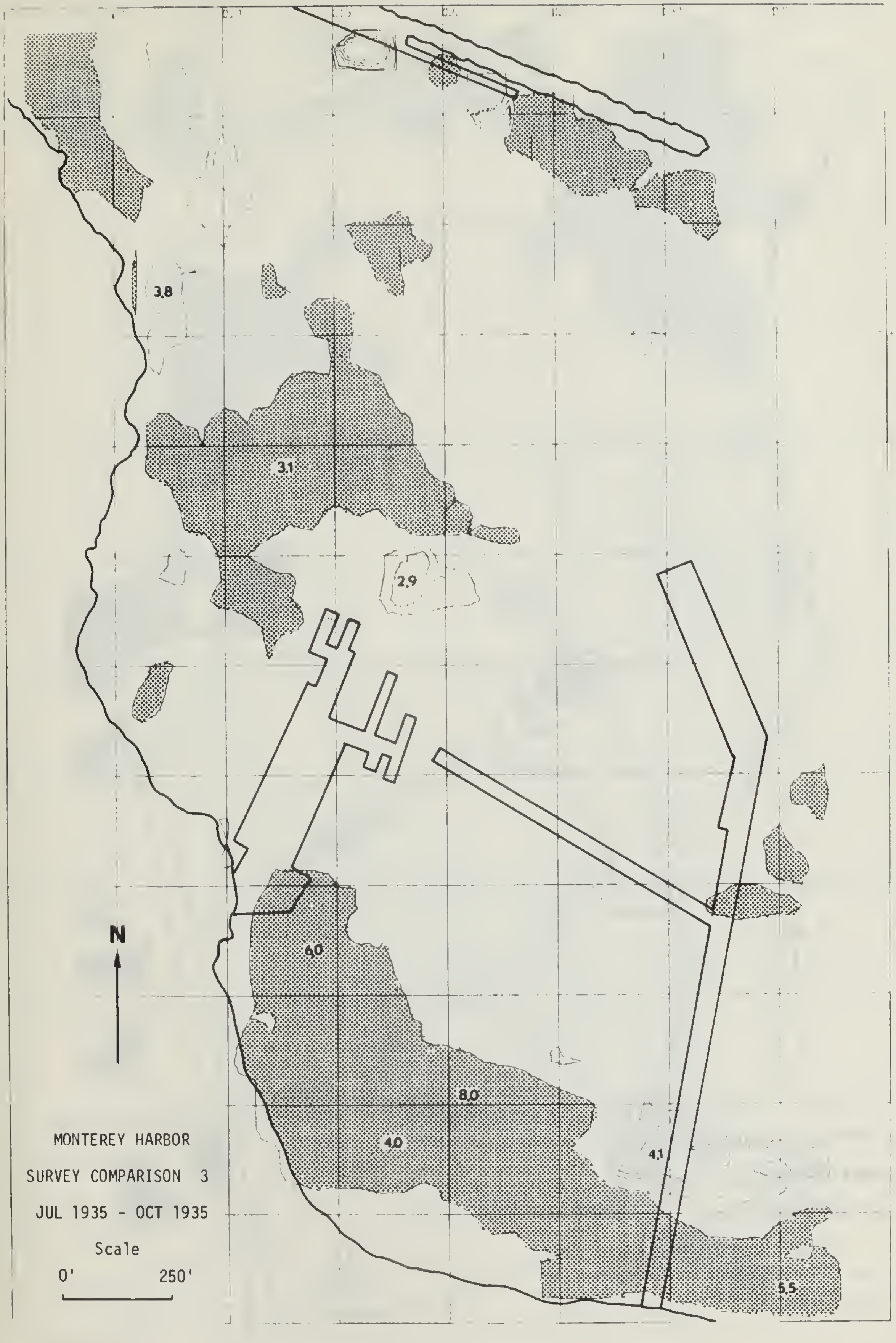
SURVEY COMPARISON 1

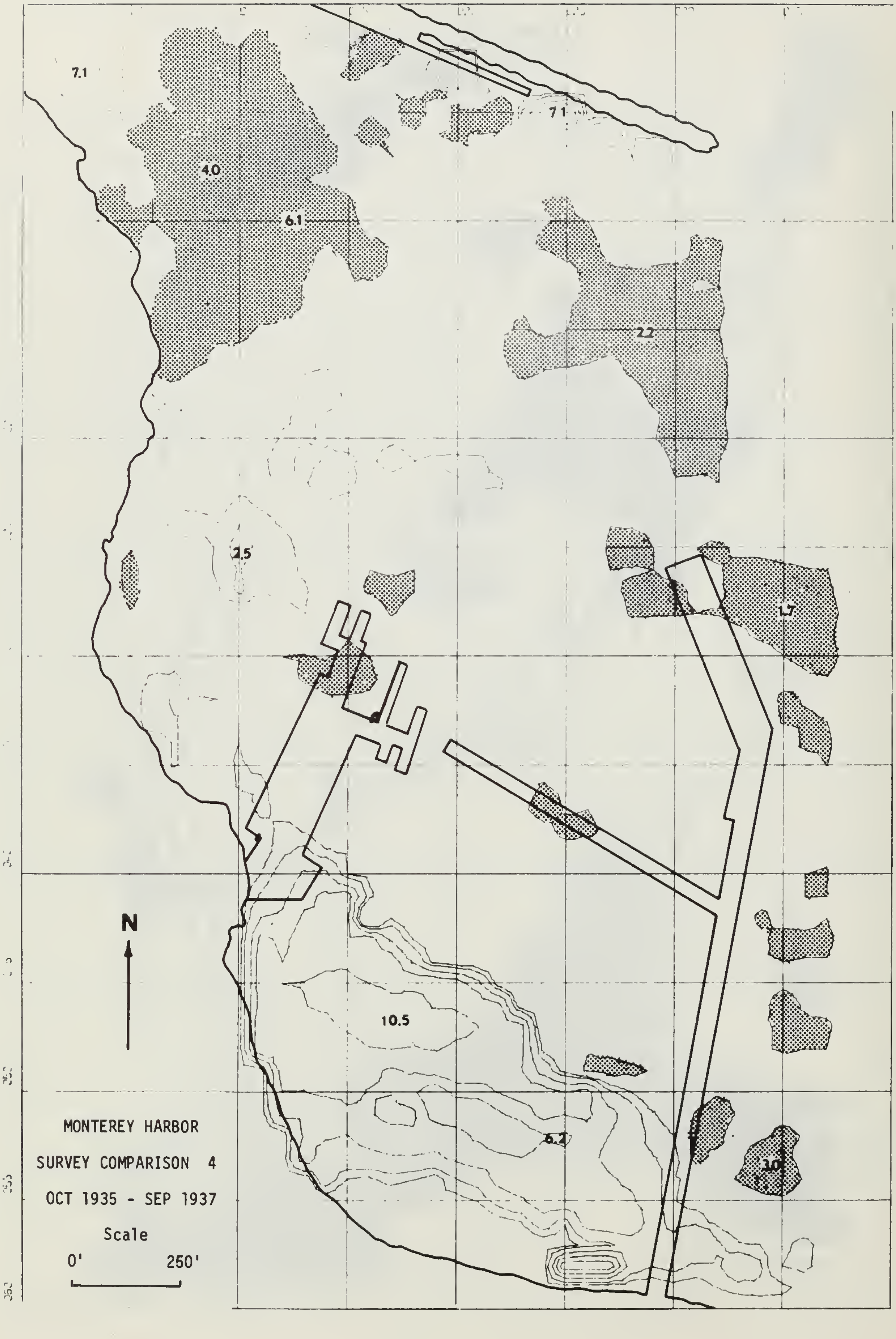
AUG 1932 - MAR 1934

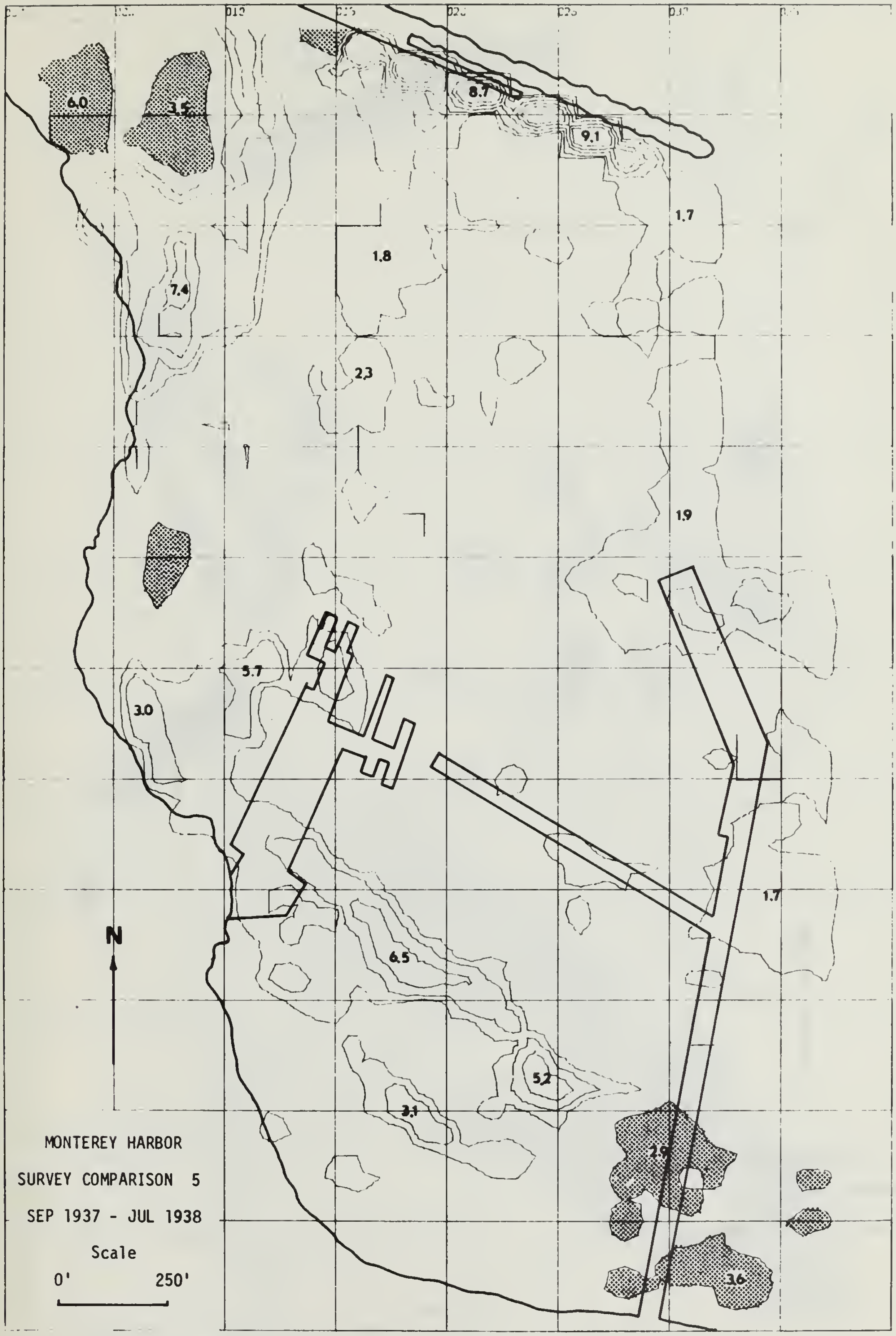
Scale

0' 250'


16.0
2.0
3.0
2.6
N
4.8
4.1
3.8
3.0
MONTEREY HARBOR
SURVEY COMPARISON 2
MAR 1934 - JUL 1935
Scale
0'
250'


3.8
3.1
2.9
N
6.0
8.0
4.0
4.1
5.5
MONTEREY HARBOR
SURVEY COMPARISON 3
JUL 1935 - OCT 1935
Scale
0'
250'

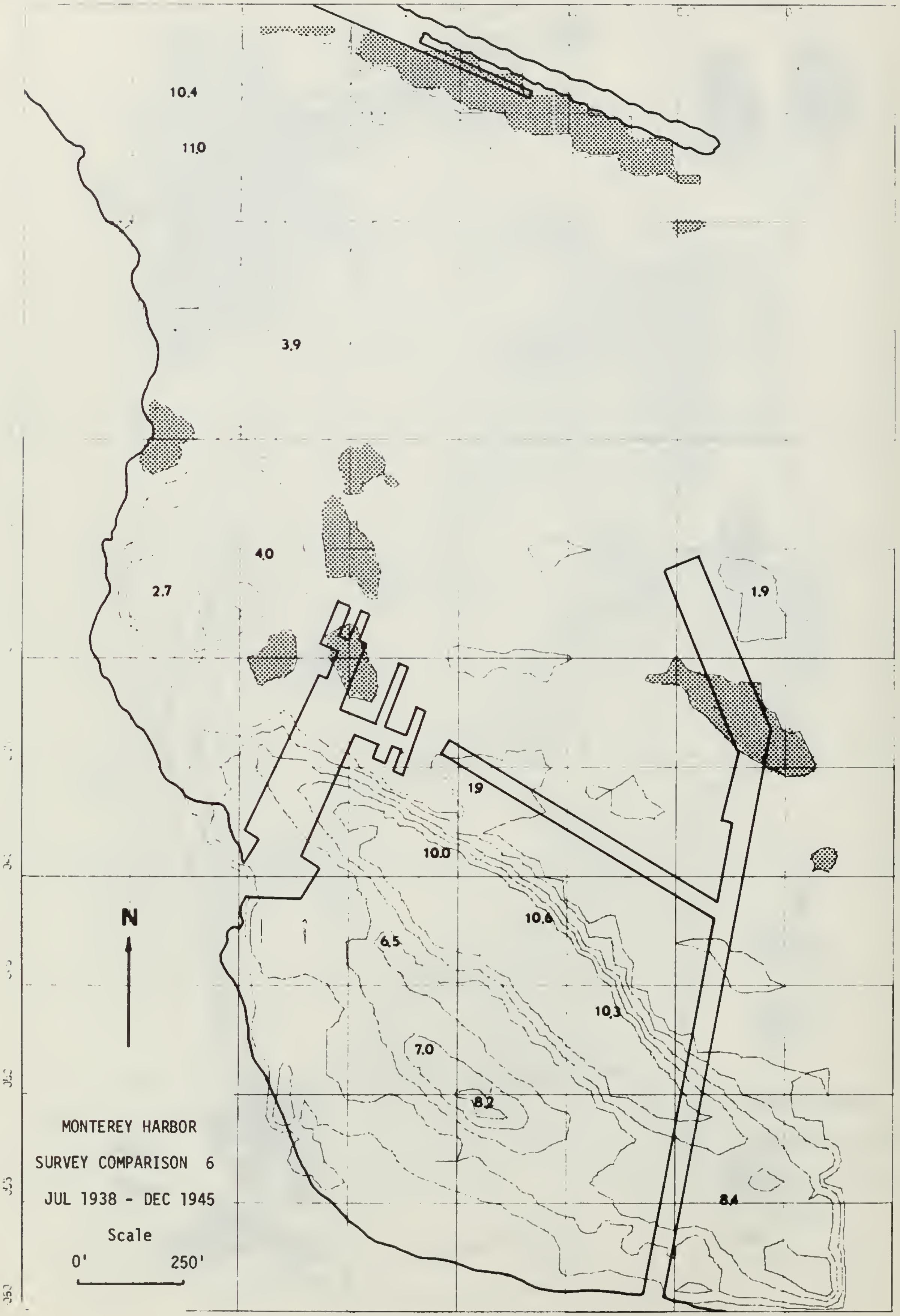

7.1
4.0
6.1
7.1
2.2
2.5
1.7
N
10.5
6.2
3.0
MONTEREY HARBOR
SURVEY COMPARISON 4
OCT 1935 - SEP 1937
Scale
0'
250'

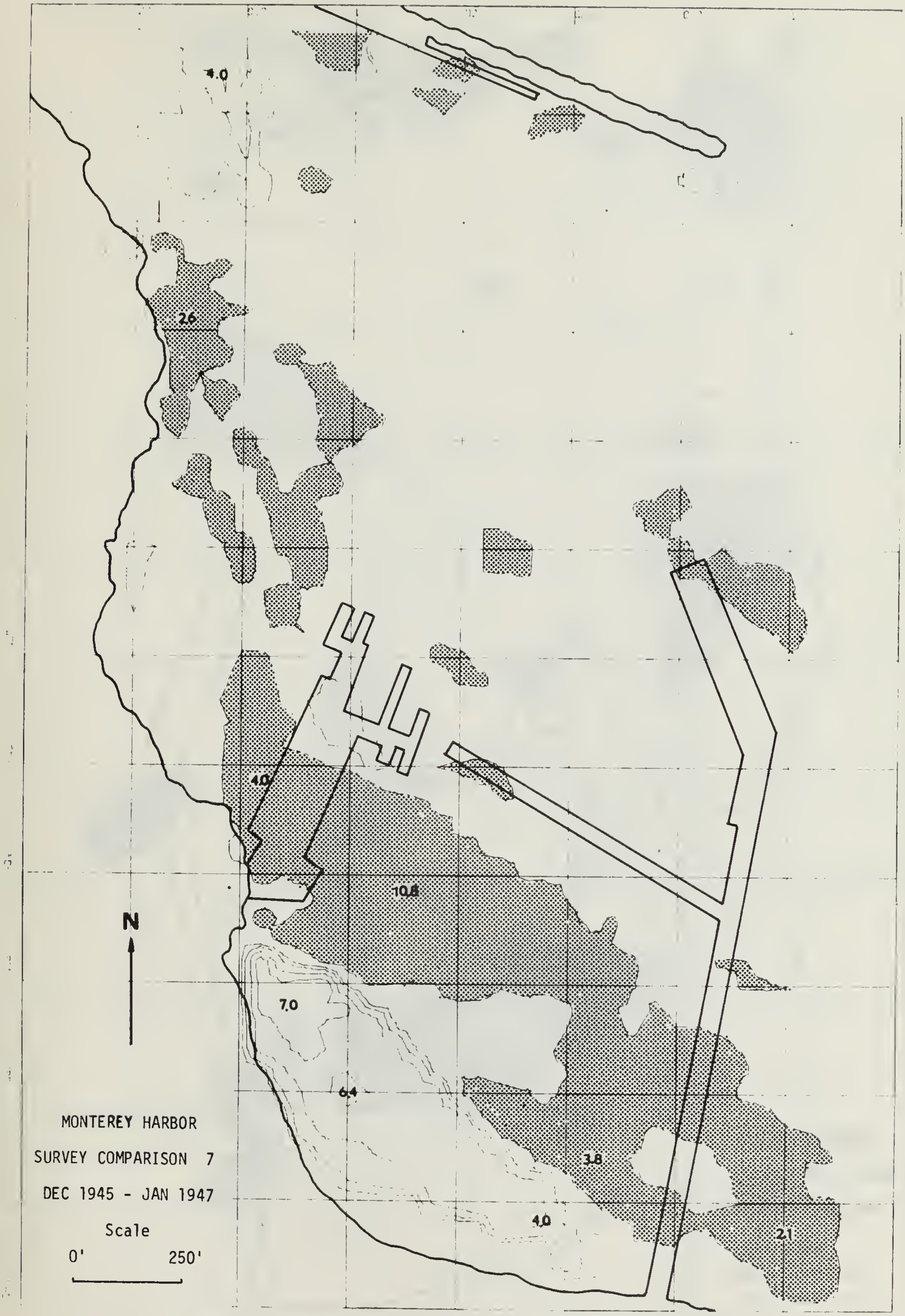


MONTEREY HARBOR

SURVEY COMPARISON 5

SEP 1937 - JUL 1938


10.4
11.0
3.9
4.0
2.7
1.9
1.9
10.0
10.6
6.5
10.3
7.0
8.2
8.4
N
MONTEREY HARBOR
SURVEY COMPARISON 6
JUL 1938 - DEC 1945
Scale
0'
250'



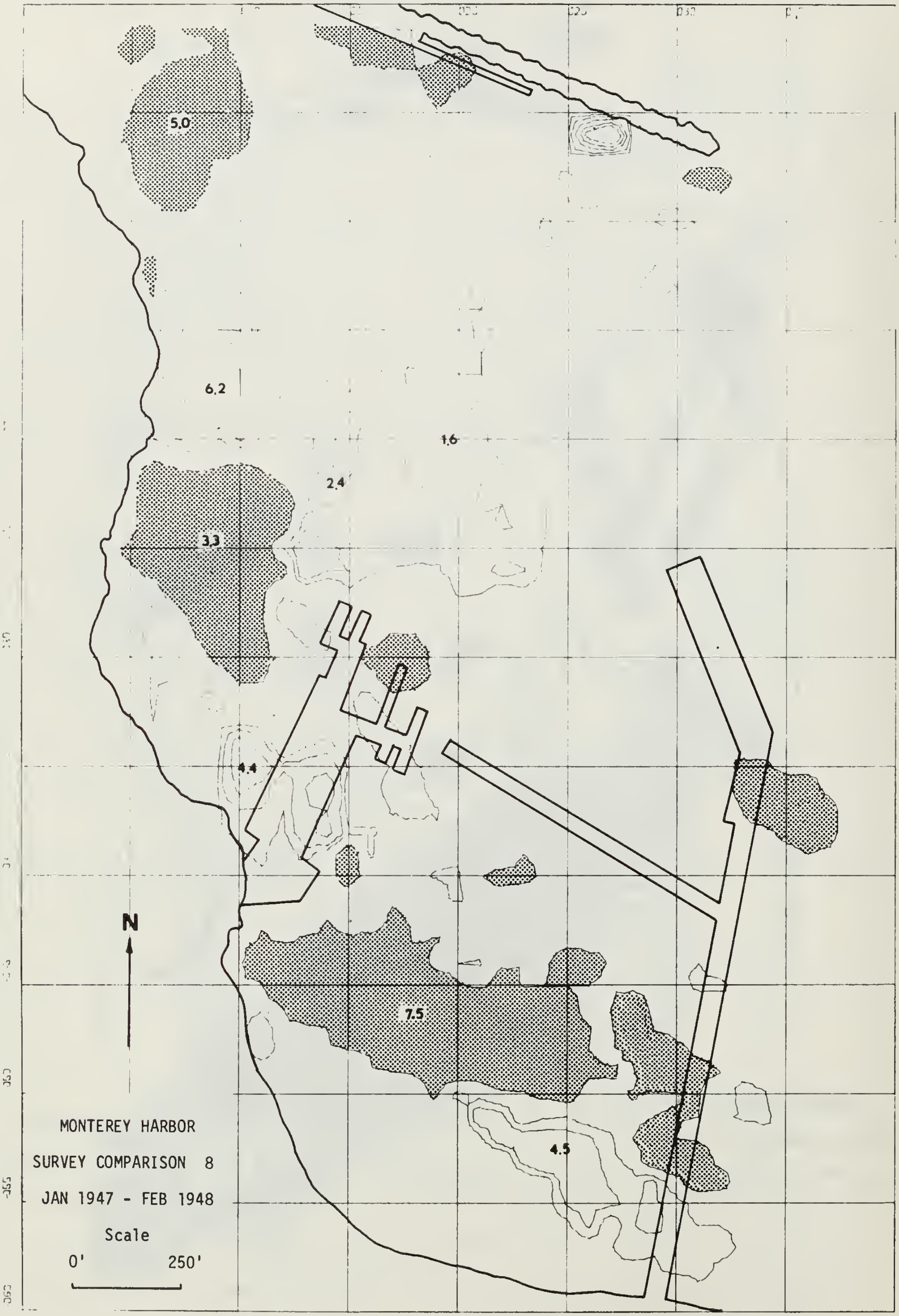
MONTEREY HARBOR

SURVEY COMPARISON 7

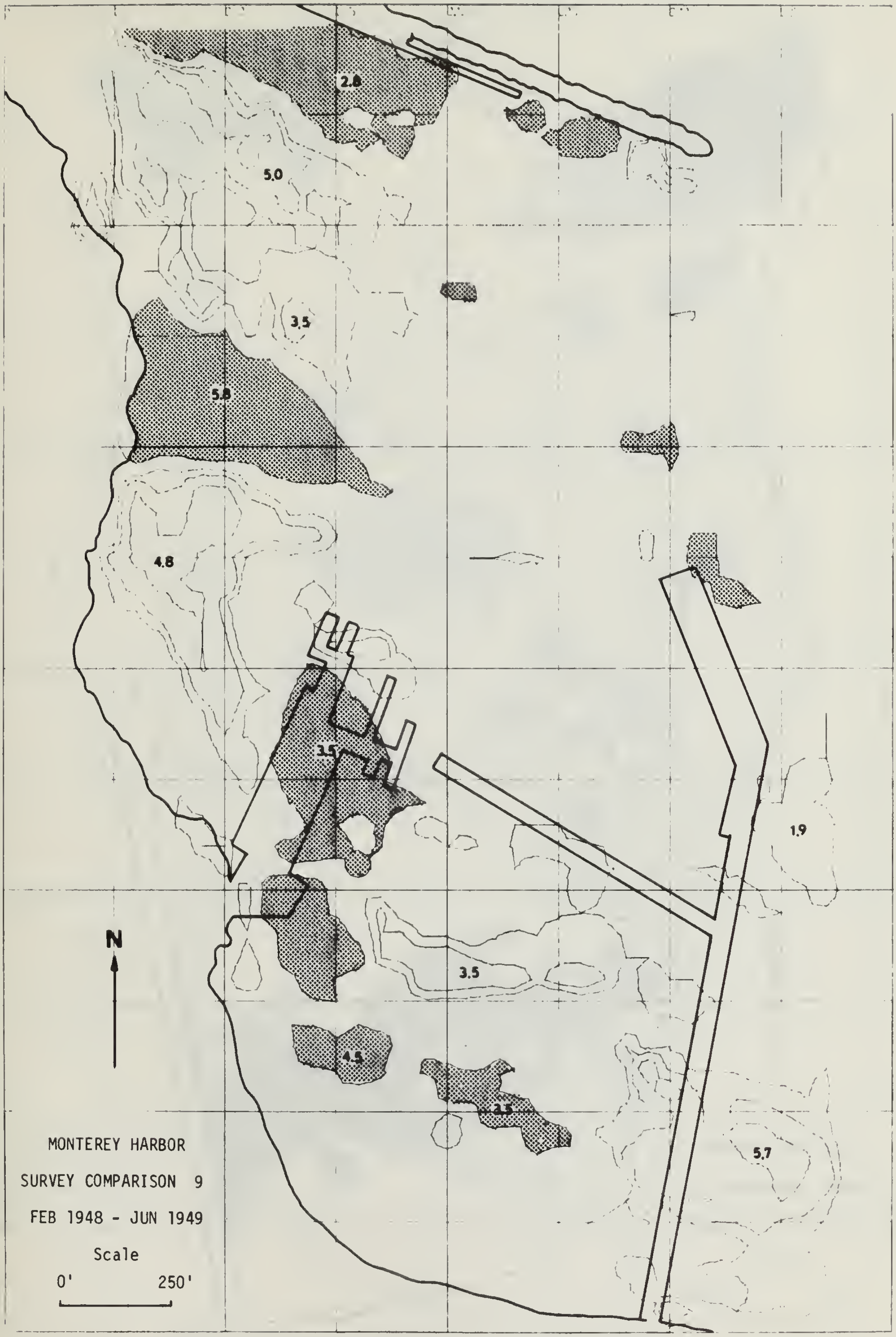
DEC 1945 - JAN 1947

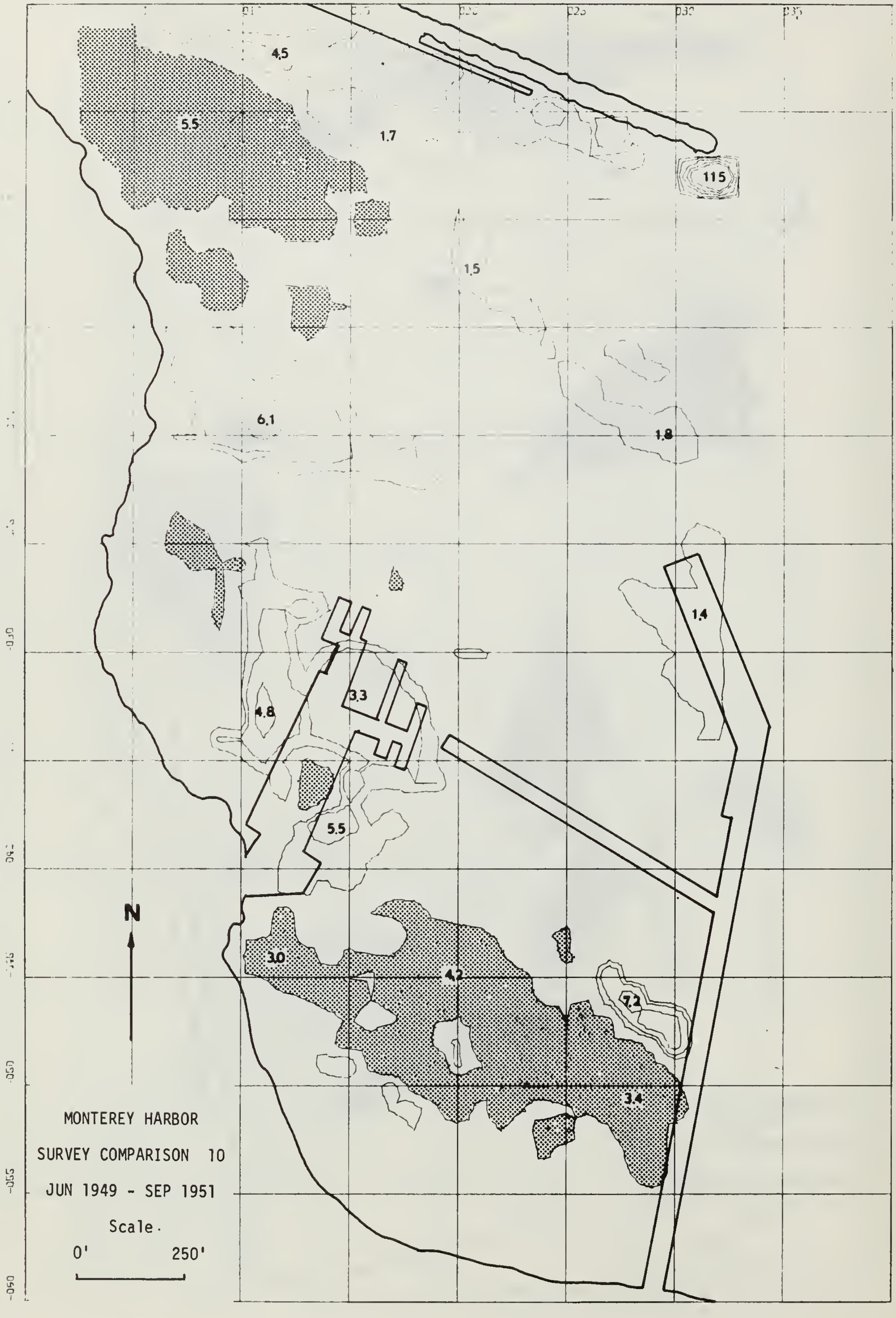
Scale

0' 250'



MONTEREY HARBOR
SURVEY COMPARISON 8
JAN 1947 - FEB 1948
Scale
0' 250'


2.8
5.0
3.5
5.8
4.8
3.5
1.9
N
3.5
4.5
3.5
5.7
MONTEREY HARBOR
SURVEY COMPARISON 9
FEB 1948 - JUN 1949
Scale
0'
250'



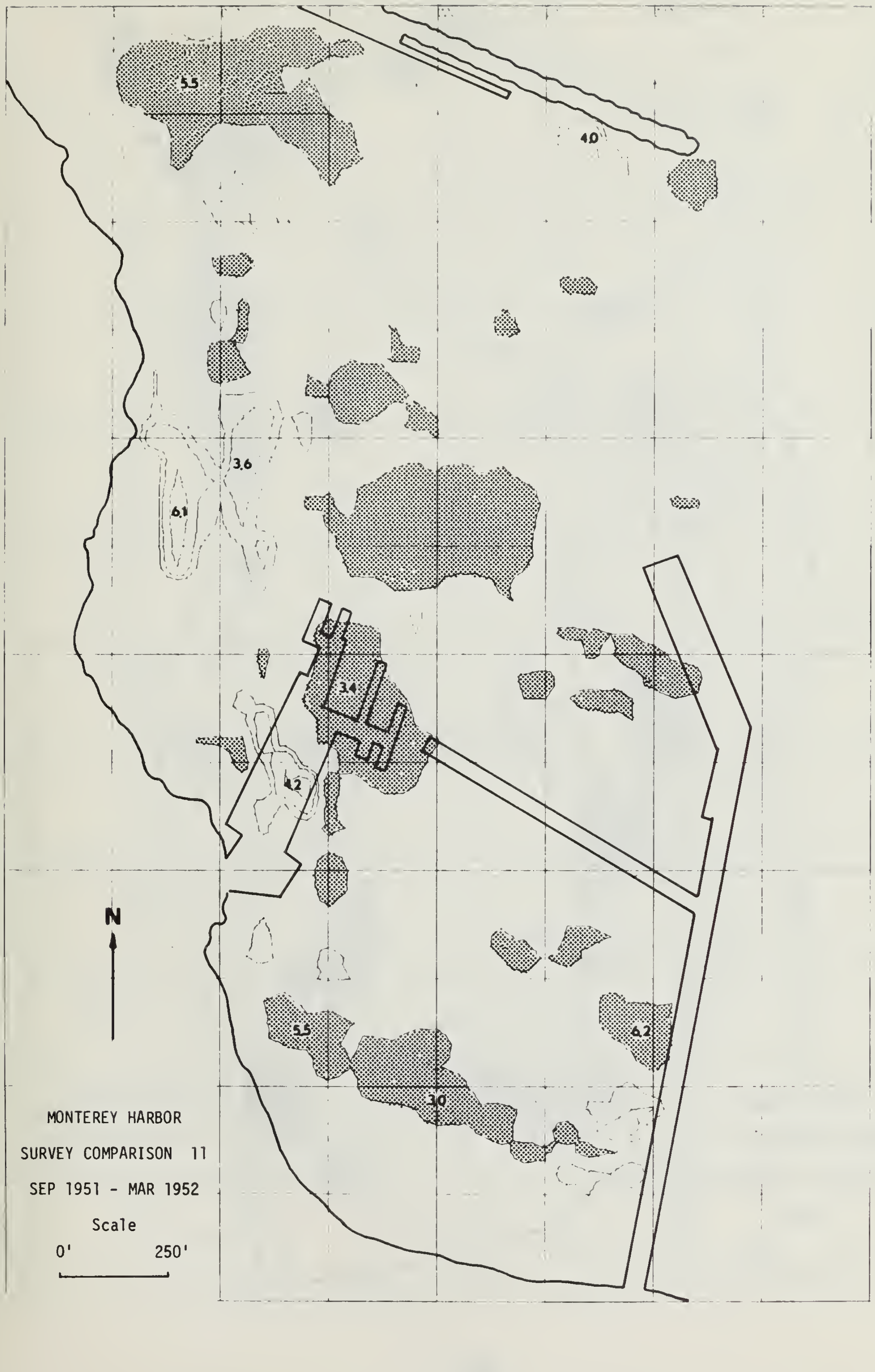
MONTEREY HARBOR

SURVEY COMPARISON 10

JUN 1949 - SEP 1951

Scale.

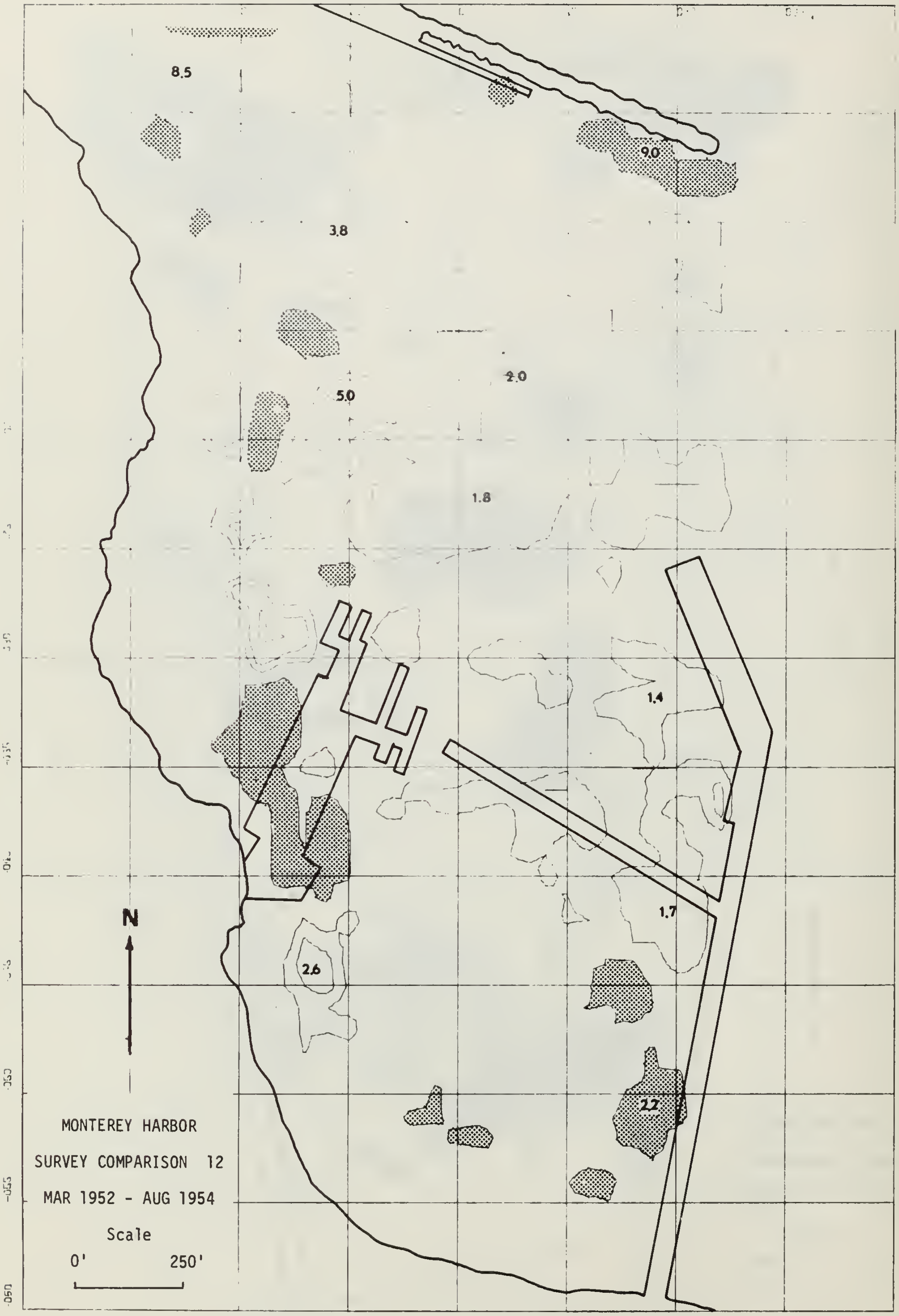
0' 250'

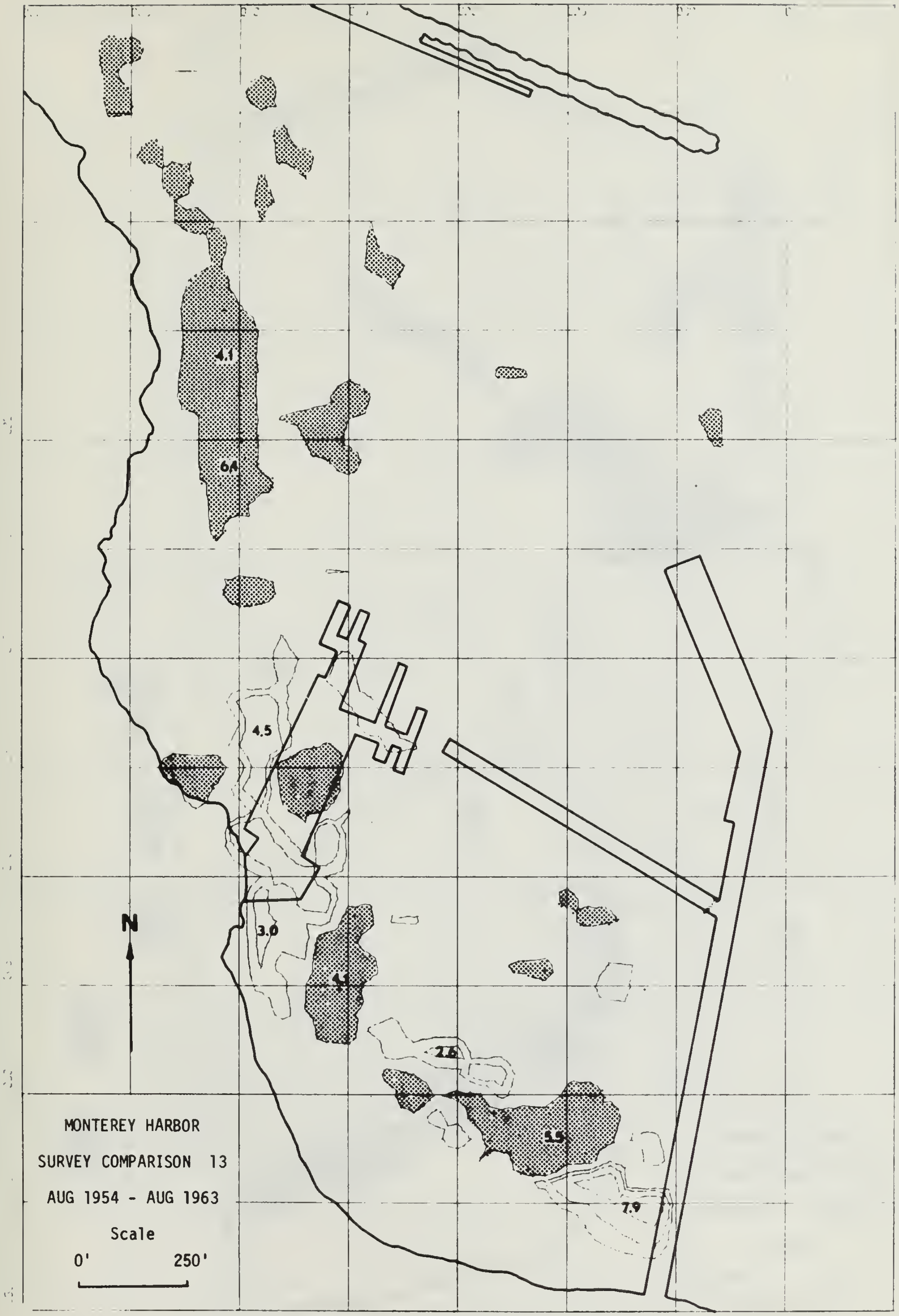


MONTEREY HARBOR

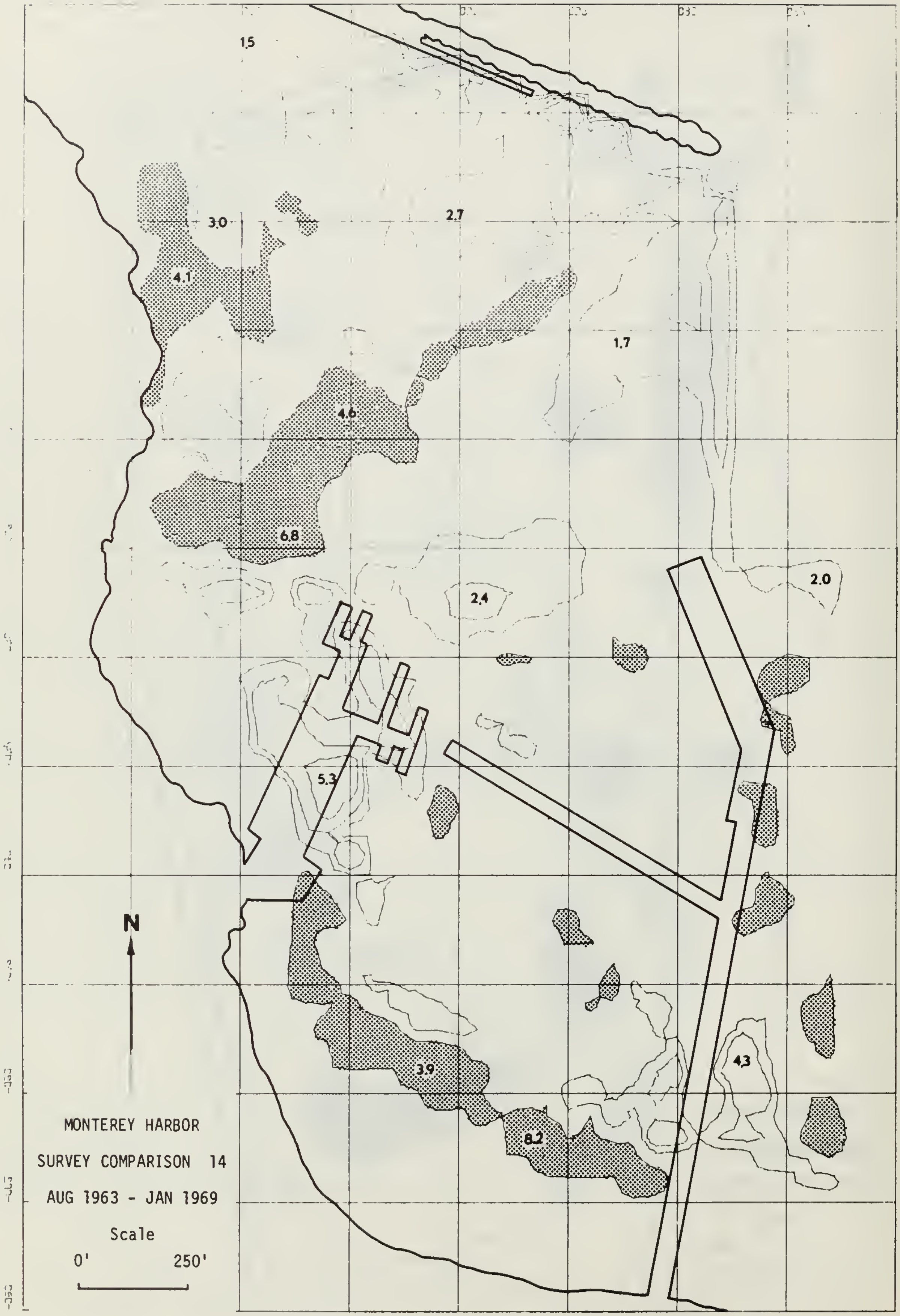
SURVEY COMPARISON 11

SEP 1951 - MAR 1952


8.5
9.0
3.8
2.0
5.0
1.8
1.4
1.7
2.6
2.7
N
MONTEREY HARBOR
SURVEY COMPARISON 12
MAR 1952 - AUG 1954
Scale
0'
250'



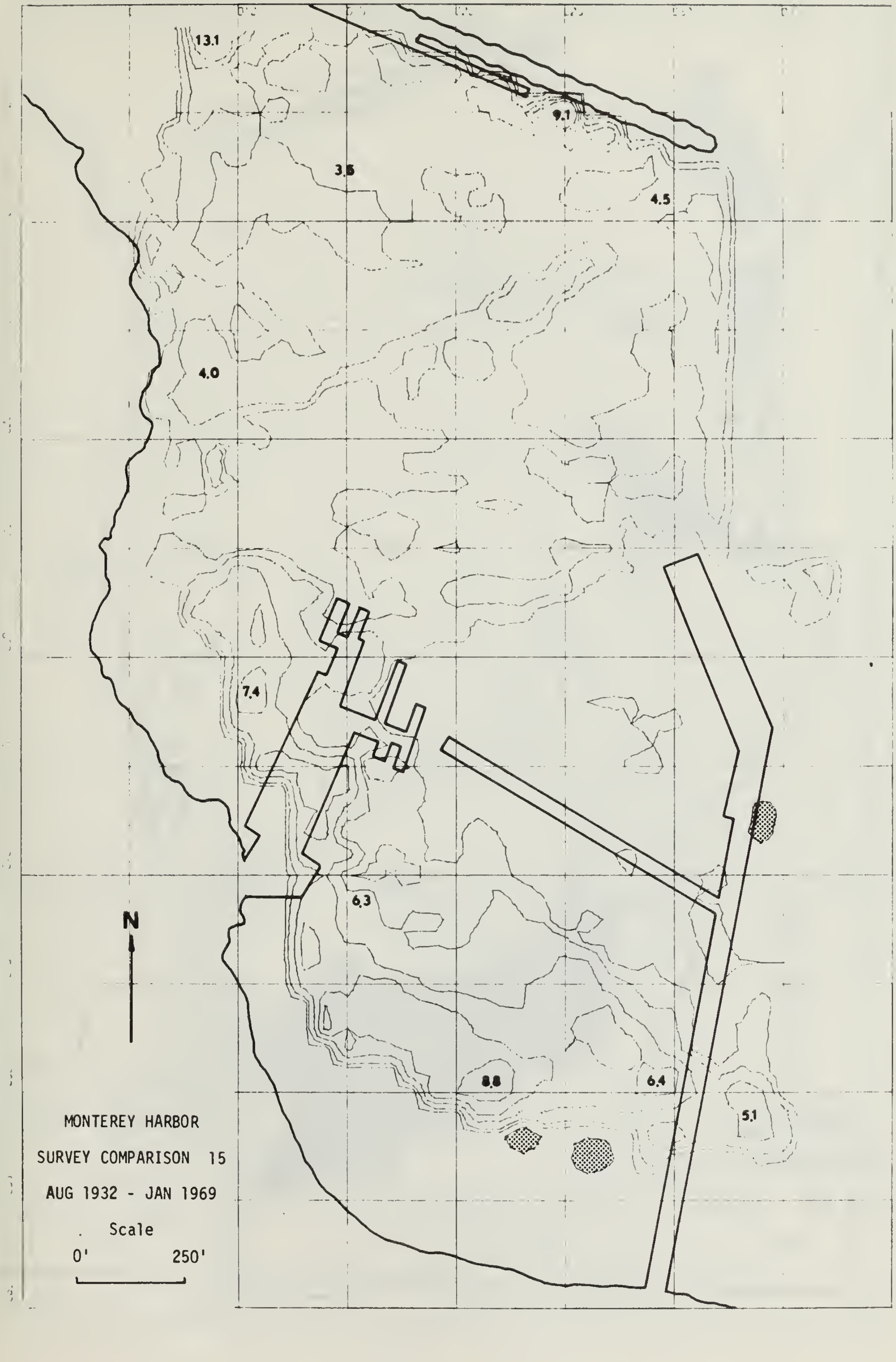
MONTEREY HARBOR
SURVEY COMPARISON 13
AUG 1954 - AUG 1963



MONTEREY HARBOR

SURVEY COMPARISON 14

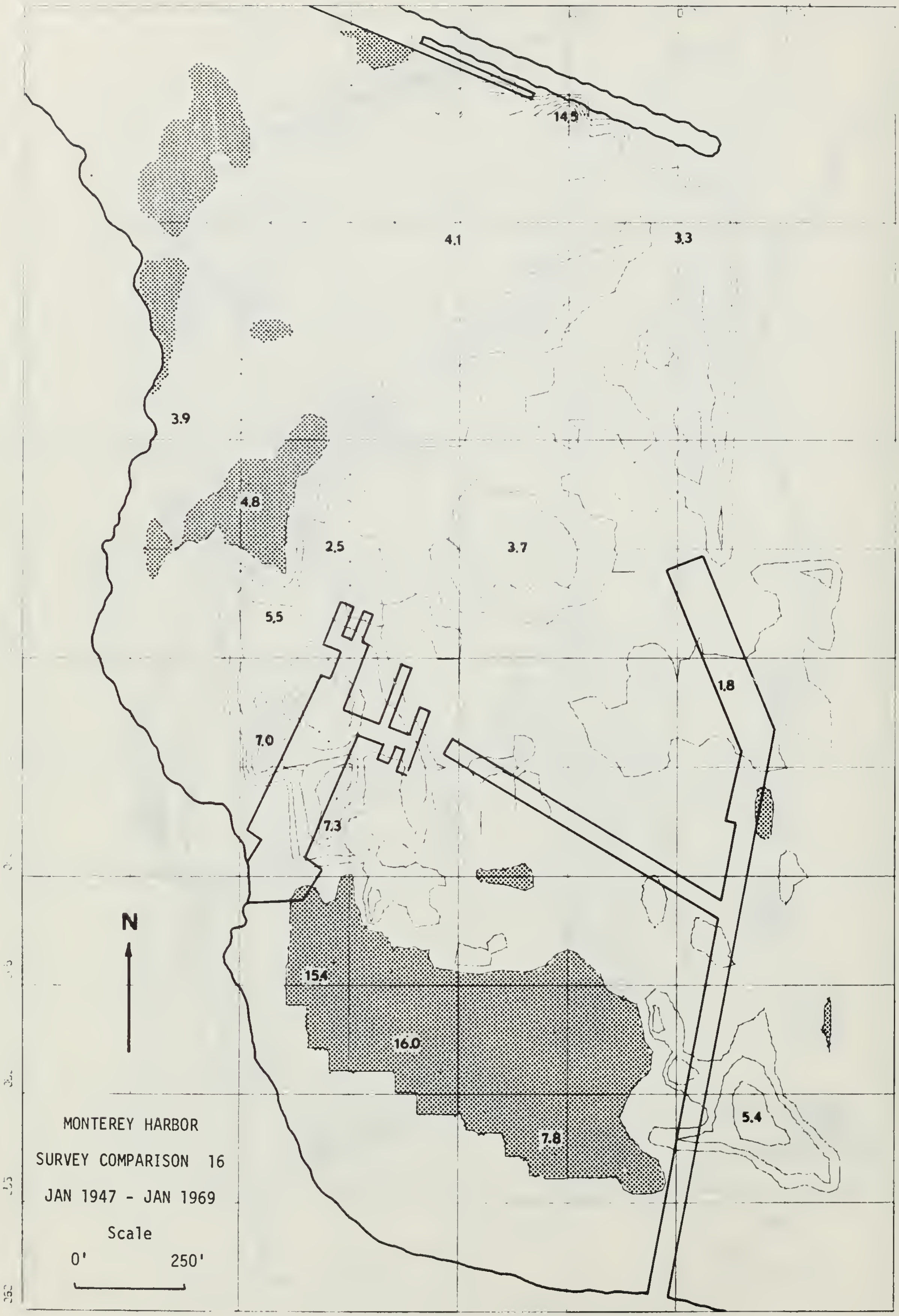
AUG 1963 - JAN 1969

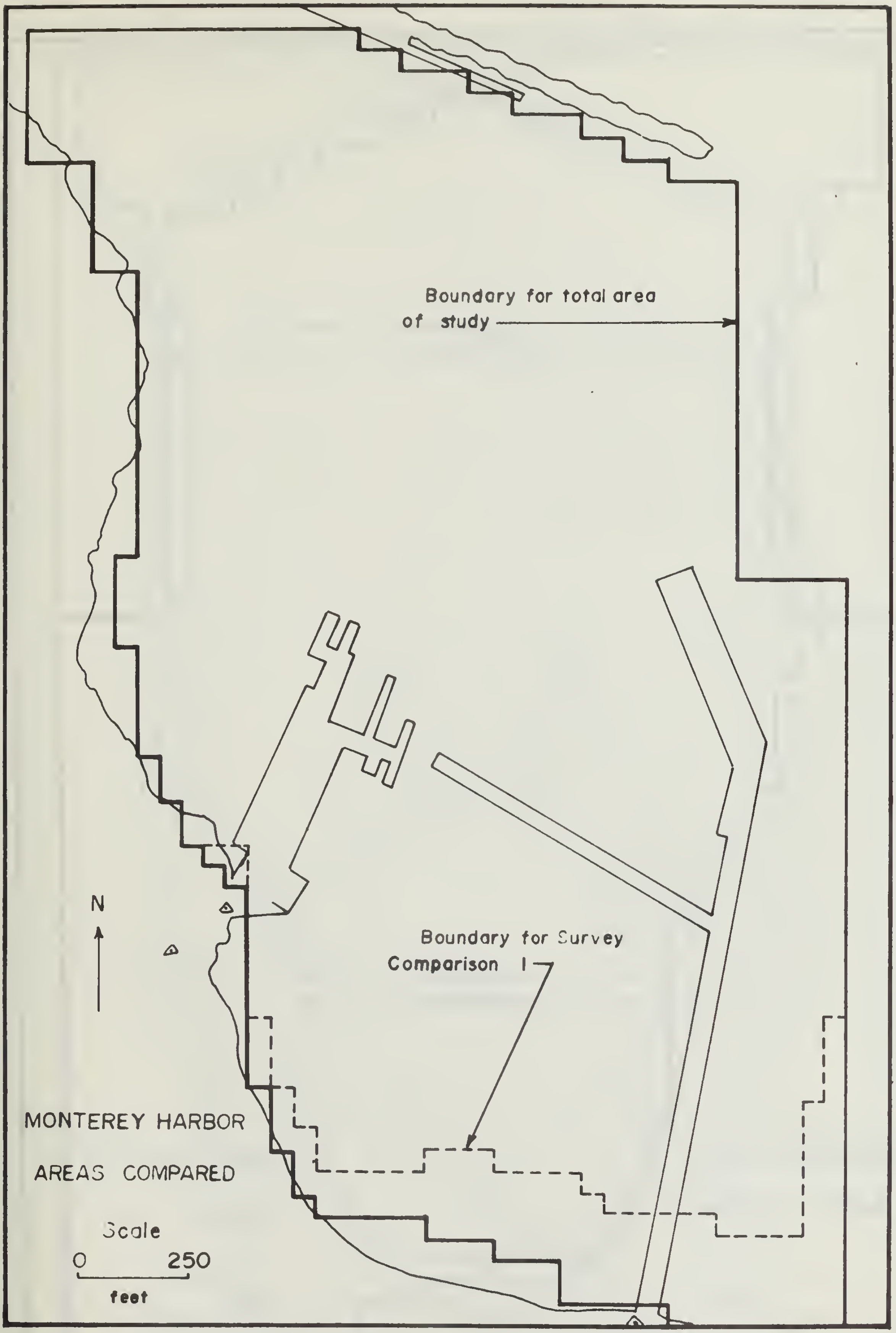


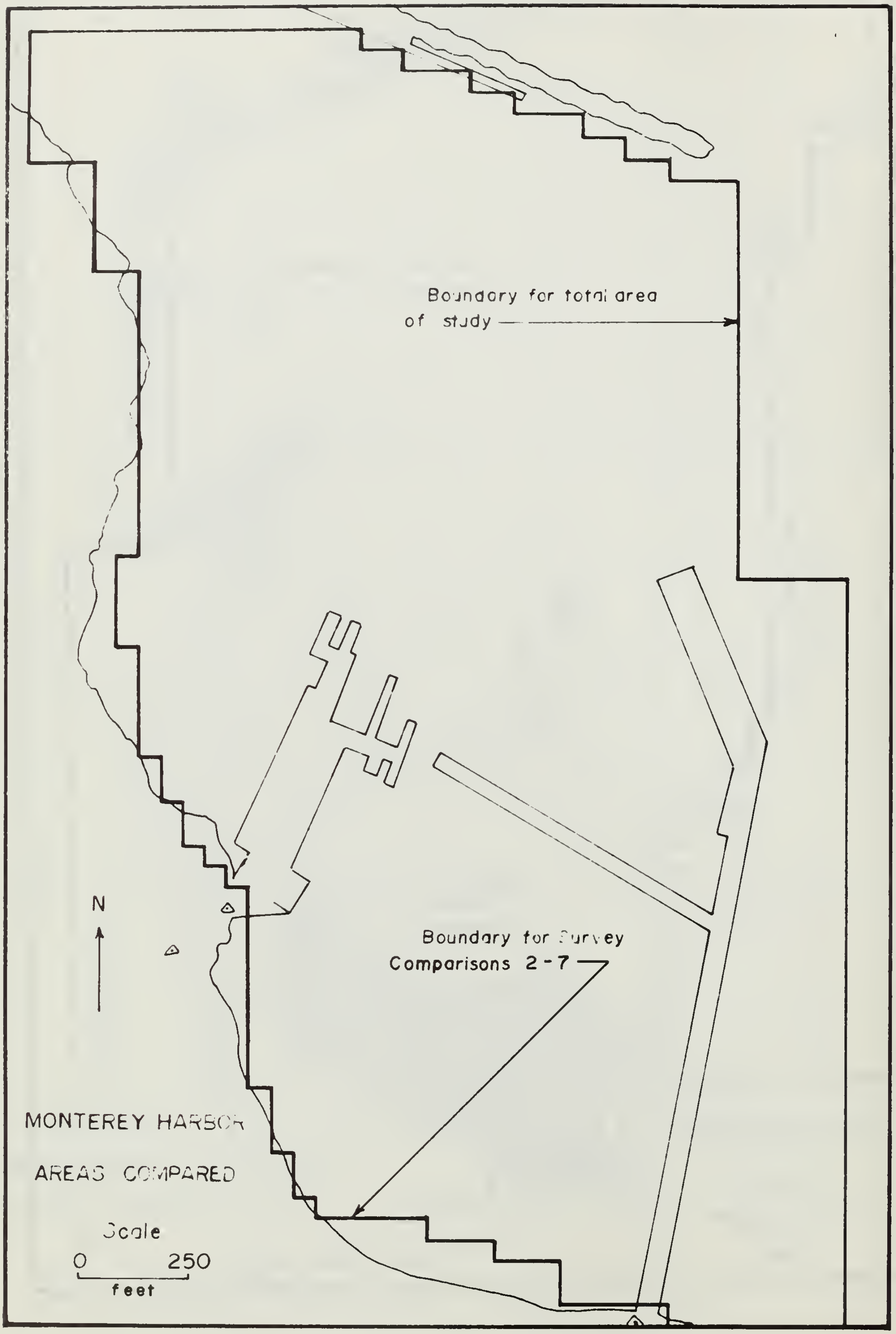
MONTEREY HARBOR

SURVEY COMPARISON 15

AUG 1932 - JAN 1969

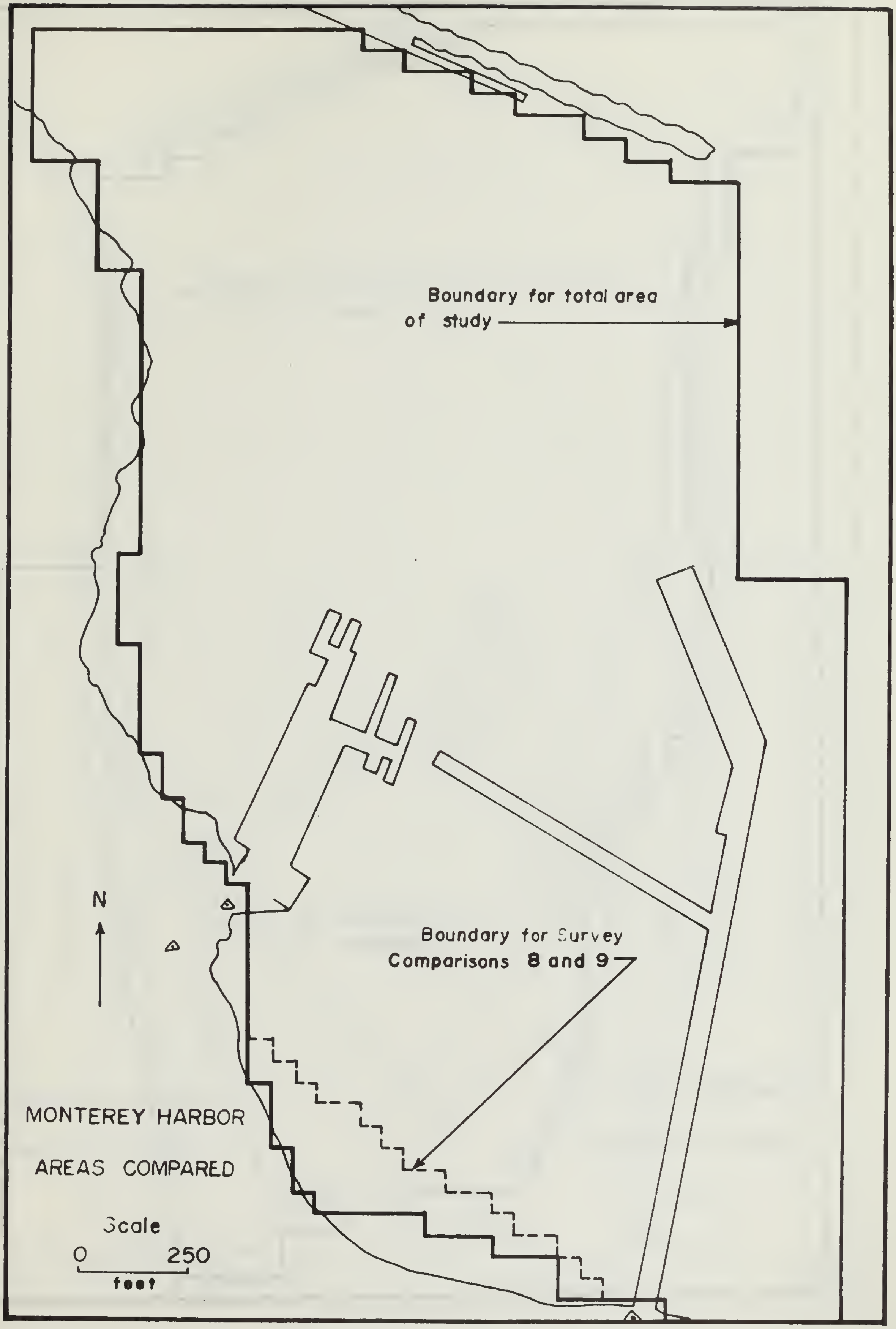

14.5
4.1
3.3
3.9
4.8
2.5
3.7
5.5
1.8
7.0
7.3
N
15.4
16.0
5.4
7.8
MONTEREY HARBOR
SURVEY COMPARISON 16
JAN 1947 - JAN 1969
Scale
0'
250'

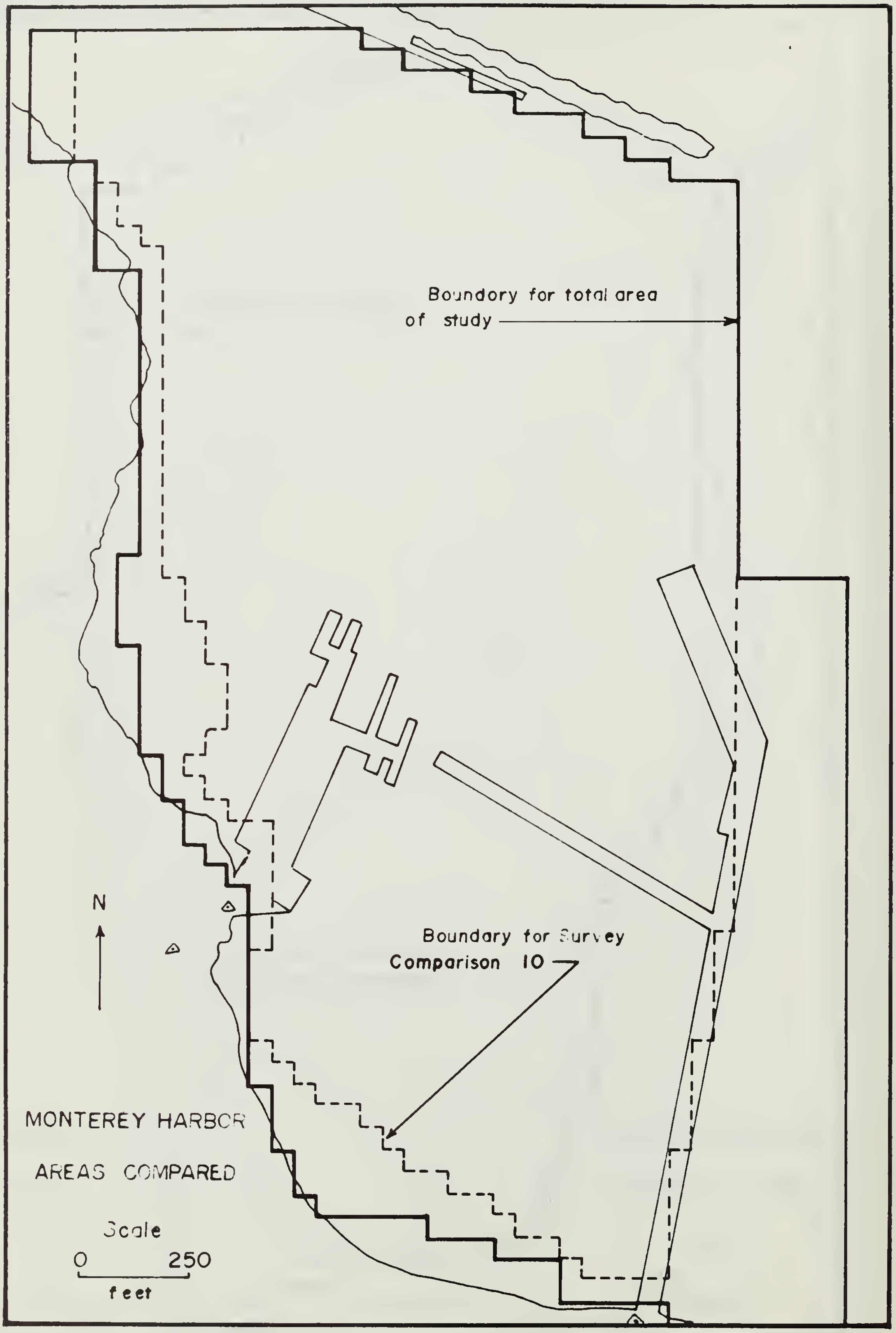

Boundary for total area of study
Boundary for Survey Comparison I
N
MONTEREY HARBOR
AREAS COMPARED
Scale
0
250
feet

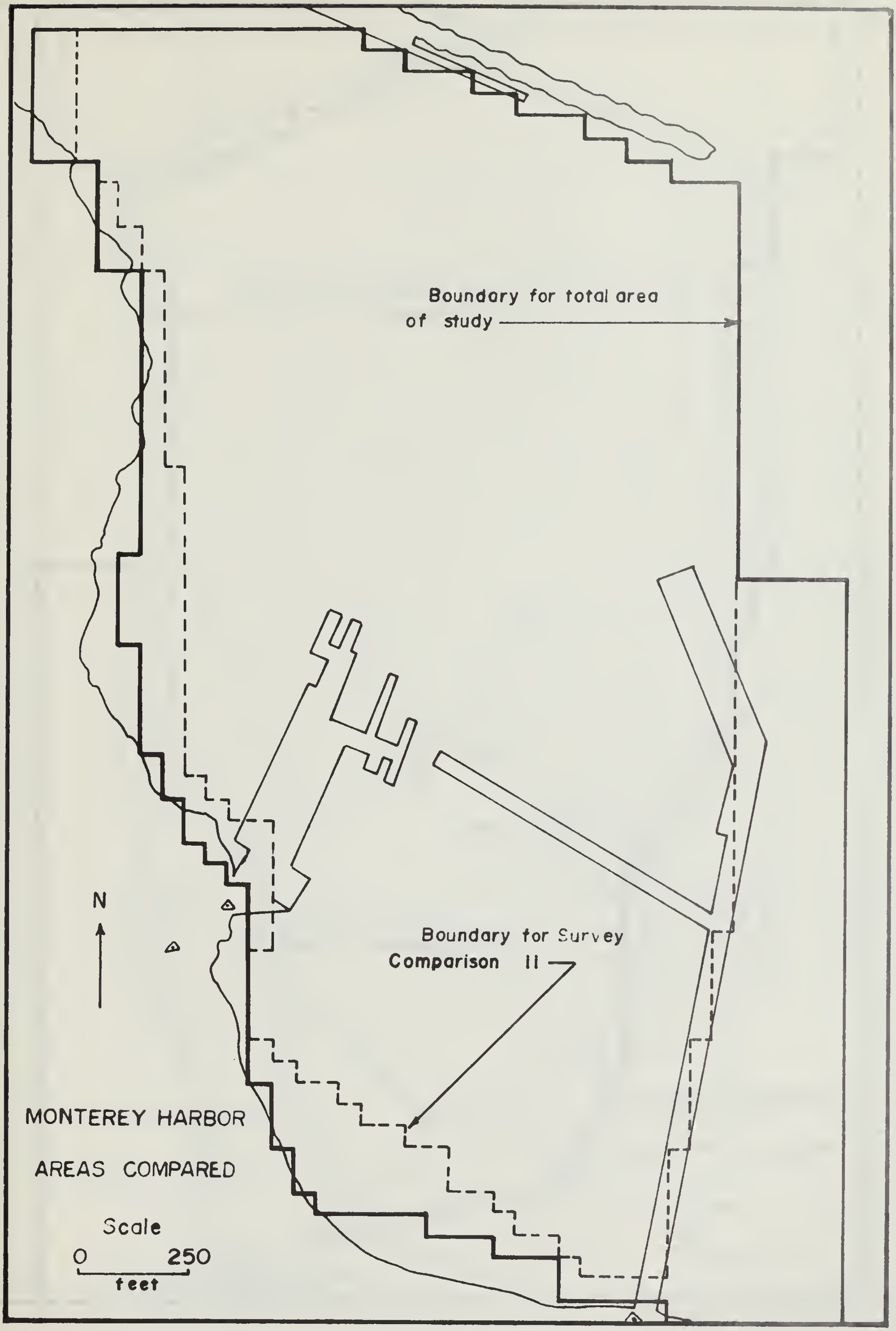


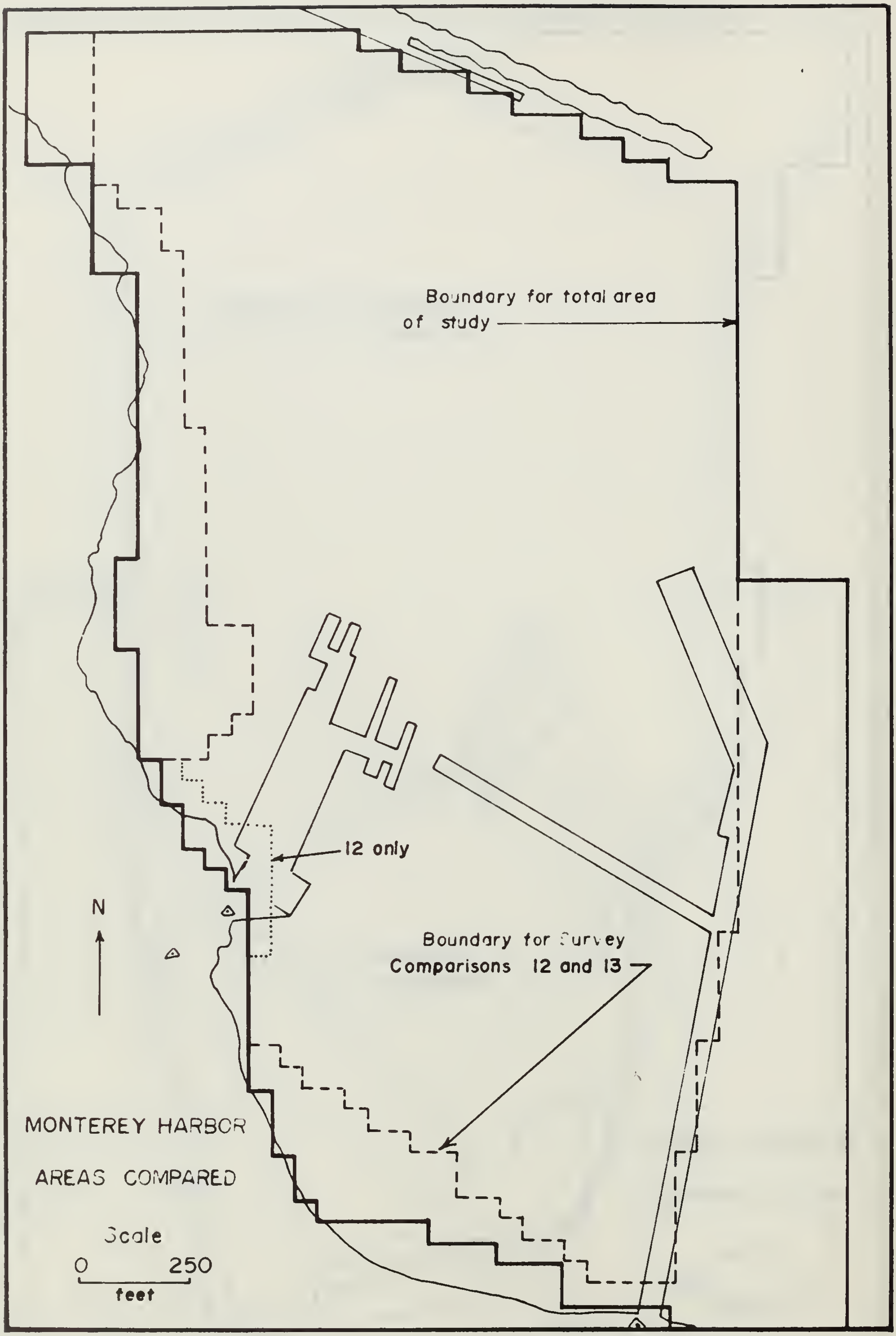
MONTEREY HARBOR

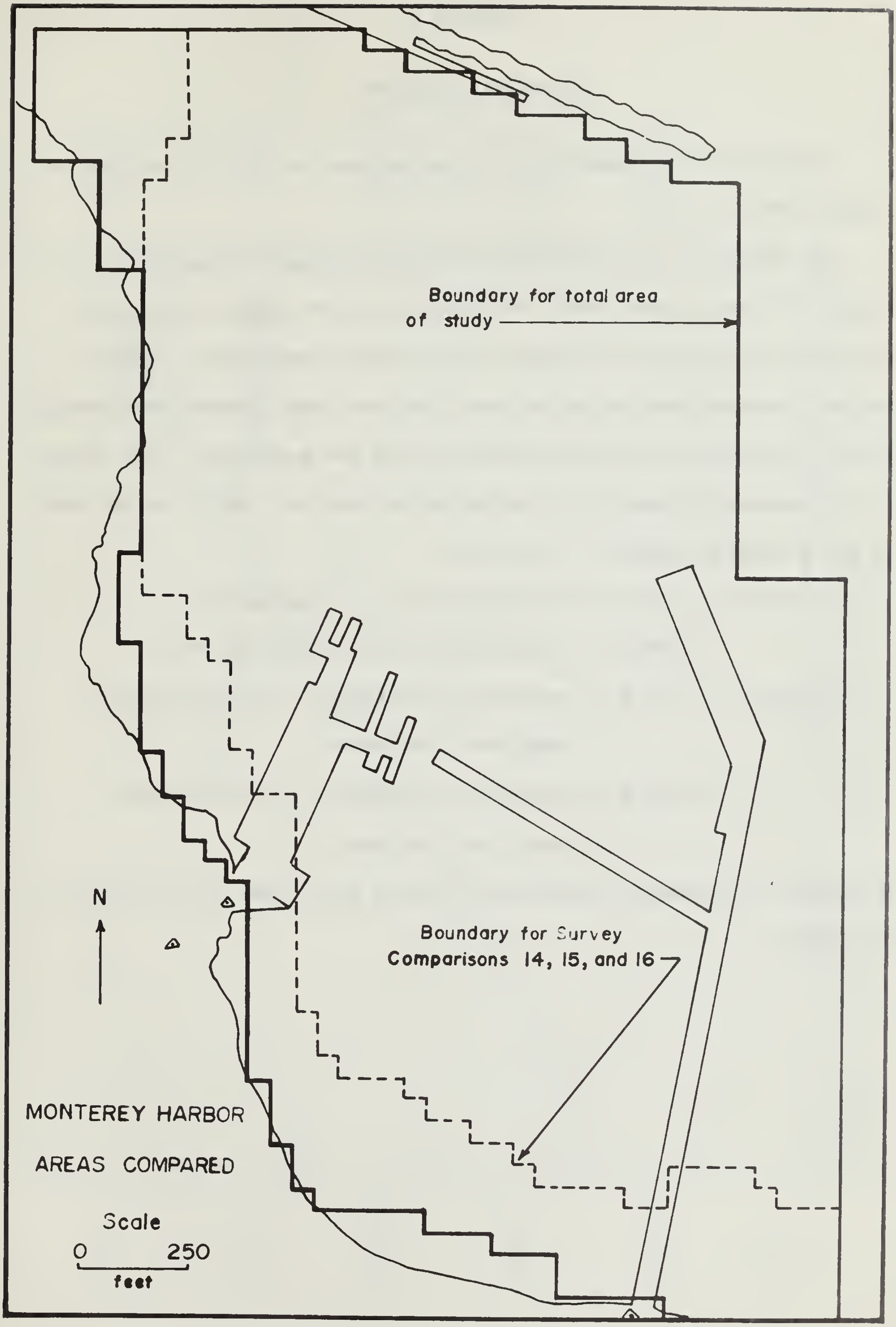
AREAS COMPARED


Boundary for total area of study
Boundary for Survey Comparisons 8 and 9
N
MONTEREY HARBOR
AREAS COMPARED
Scale
0
250
feet


Boundory for total area of study
Boundary for Survey Comparison 10
N
MONTEREY HARBOR
AREAS COMPARED
Scale
0
250
feet


Boundary for total area
of study
N
Boundary for Survey
Comparison II
MONTEREY HARBOR
AREAS COMPARED
Scale
0 250
feet


Boundary for total area of study
12 only
N
Boundary for Survey Comparisons 12 and 13
MONTEREY HARBOR
AREAS COMPARED
Scale
0
250
feet


Boundary for total area of study
Boundary for Survey Comparisons 14, 15, and 16
N
MONTEREY HARBOR
AREAS COMPARED
Scale
0
250
feet

APPENDIX C

BOTTOM-TREND CHARTS

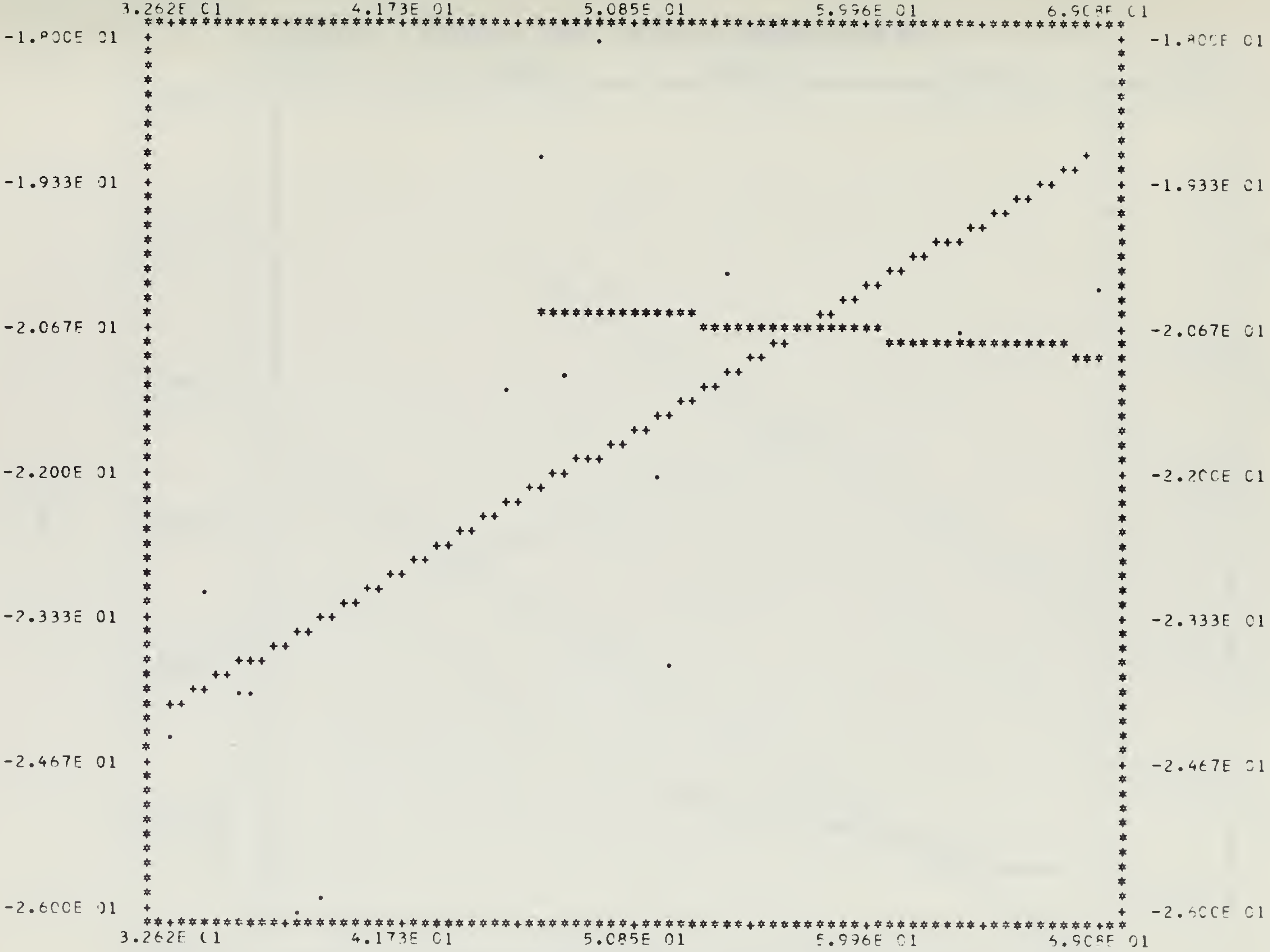
The bottom-trend graphs are presented here for the 44 grid points shown in Figures 8-11.

The ordinate on all graphs represents the span of years from August 1932 to January 1969. The abscissa is the depth relative to Mean Lower Low Water. The depth scale differs from graph to graph, and has been designed so as to cover just the range between the maximum and minimum values of depth observed at any one grid point. The scales are in computer exponential floating-point notation, which can be read as the following examples illustrate:

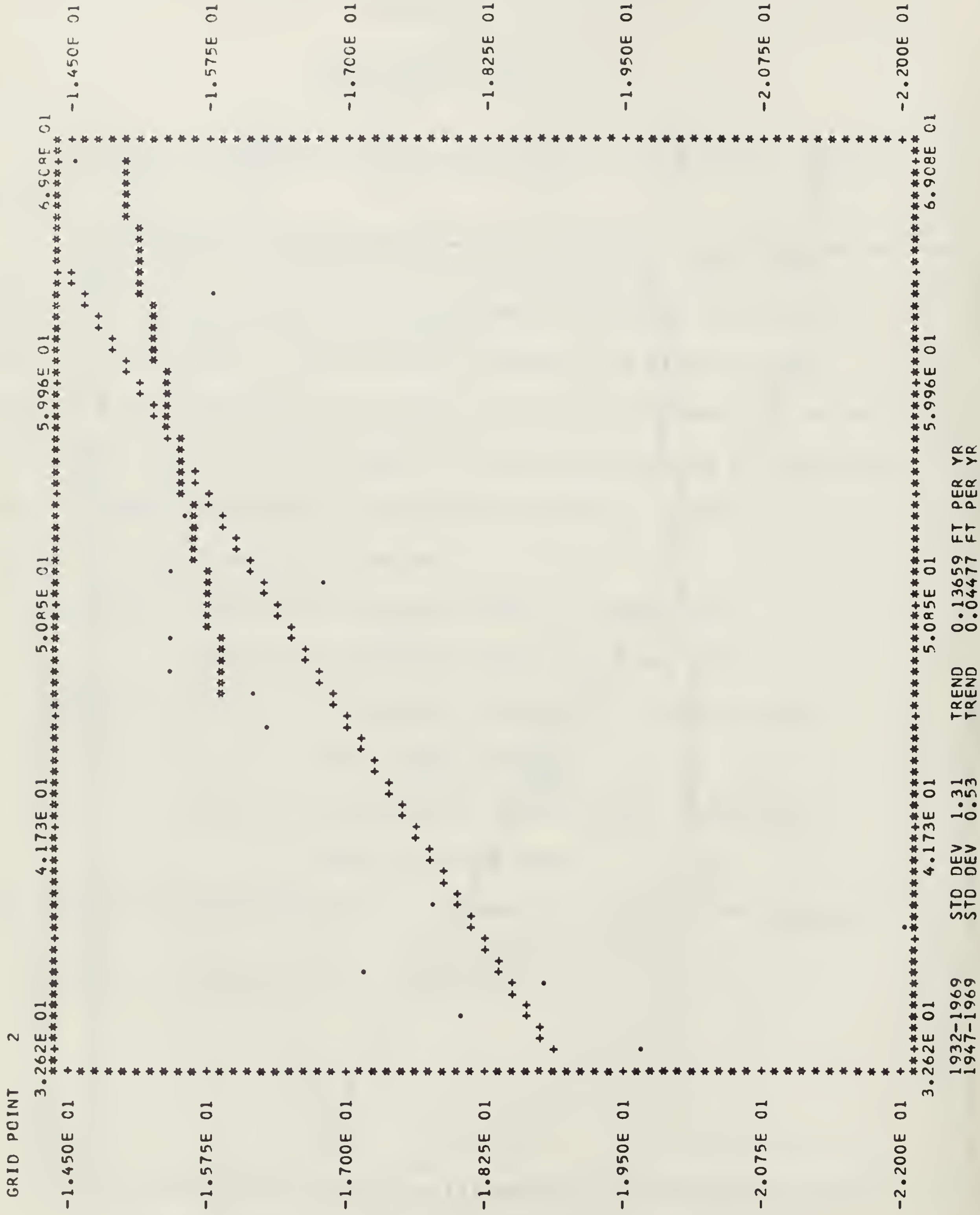
Ordinate: 3.262 E 01 represents 32.62, or August 1932
6.908 E 01 represents 69.08, or January 1969
Abscissa: 3.333 E 00 represents a height of 3.333 feet above Mean Lower Low Water
-2.200 E 01 represents a depth of 22.00 feet below Mean Lower Low Water

The trends and standard deviations in depth are listed at the bottom of each graph.

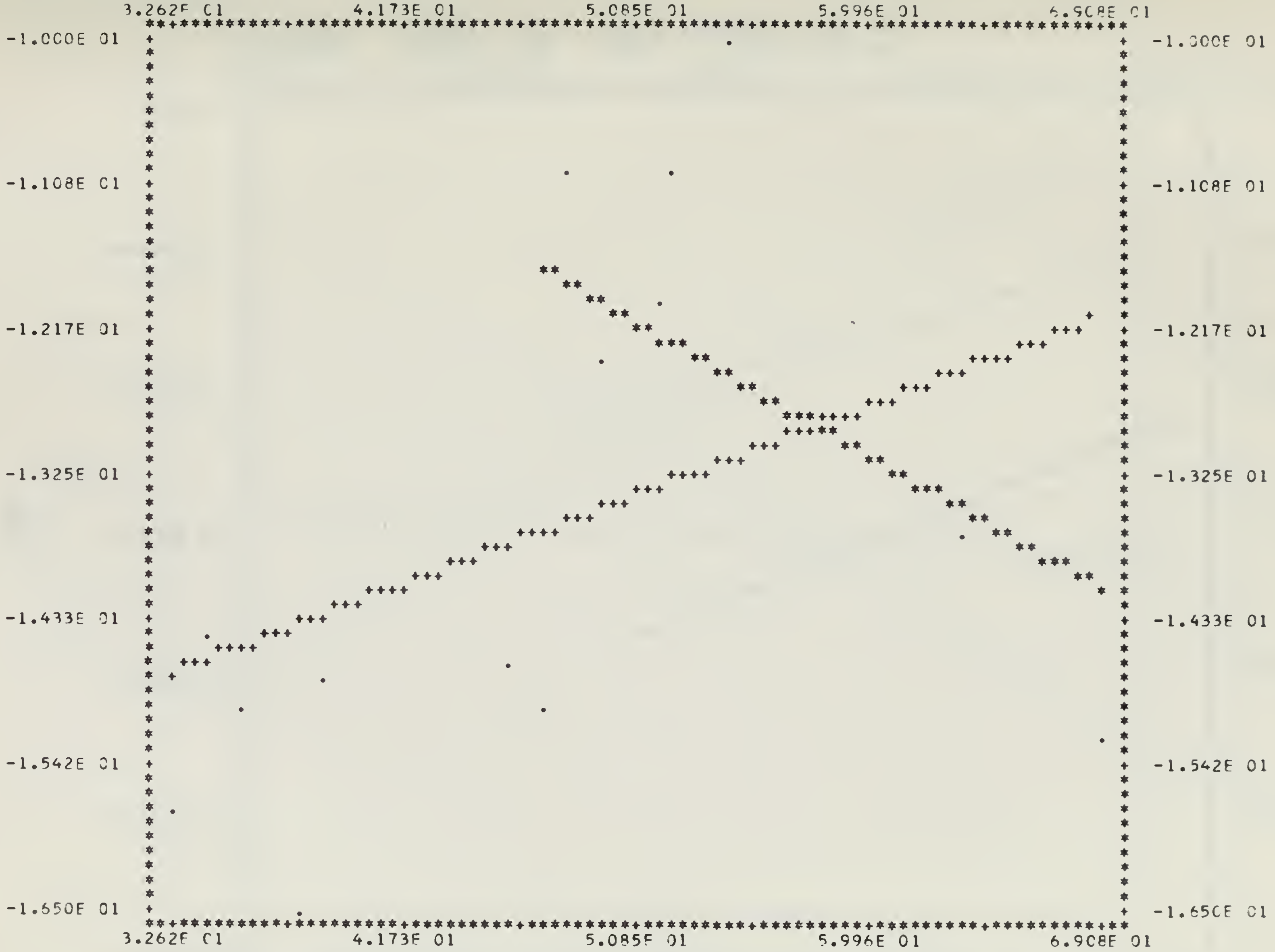
GRID POINT 1



```
1932-1969      STD DEV  1.85      TREND   0.14135 FT PER YR
1947-1969      STD DEV  1.73      TREND  -0.01810 FT PER YR
```

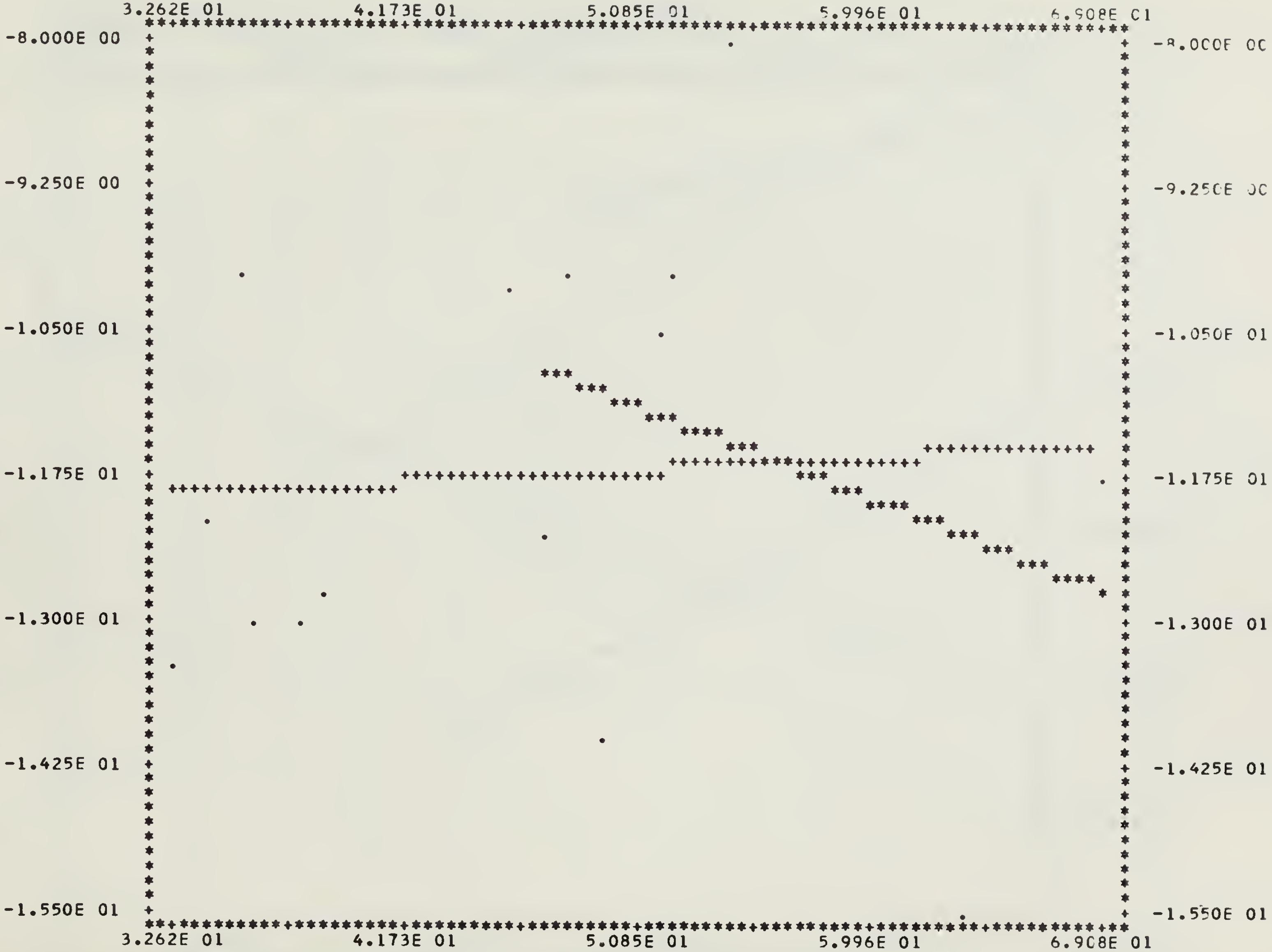

GRID POINT 2
-1.450E 01
-1.575E 01
-1.700E 01
-1.825E 01
-1.950E 01
-2.075E 01
-2.200E 01
3.262E 01
4.173E 01
5.085E 01
5.996E 01
6.908E 01
1932-1969 STD DEV 1.31 TREND 0.13659 FT PER YR
1947-1969 STD DEV 0.53 TREND 0.04477 FT PER YR

GRID POINT 3



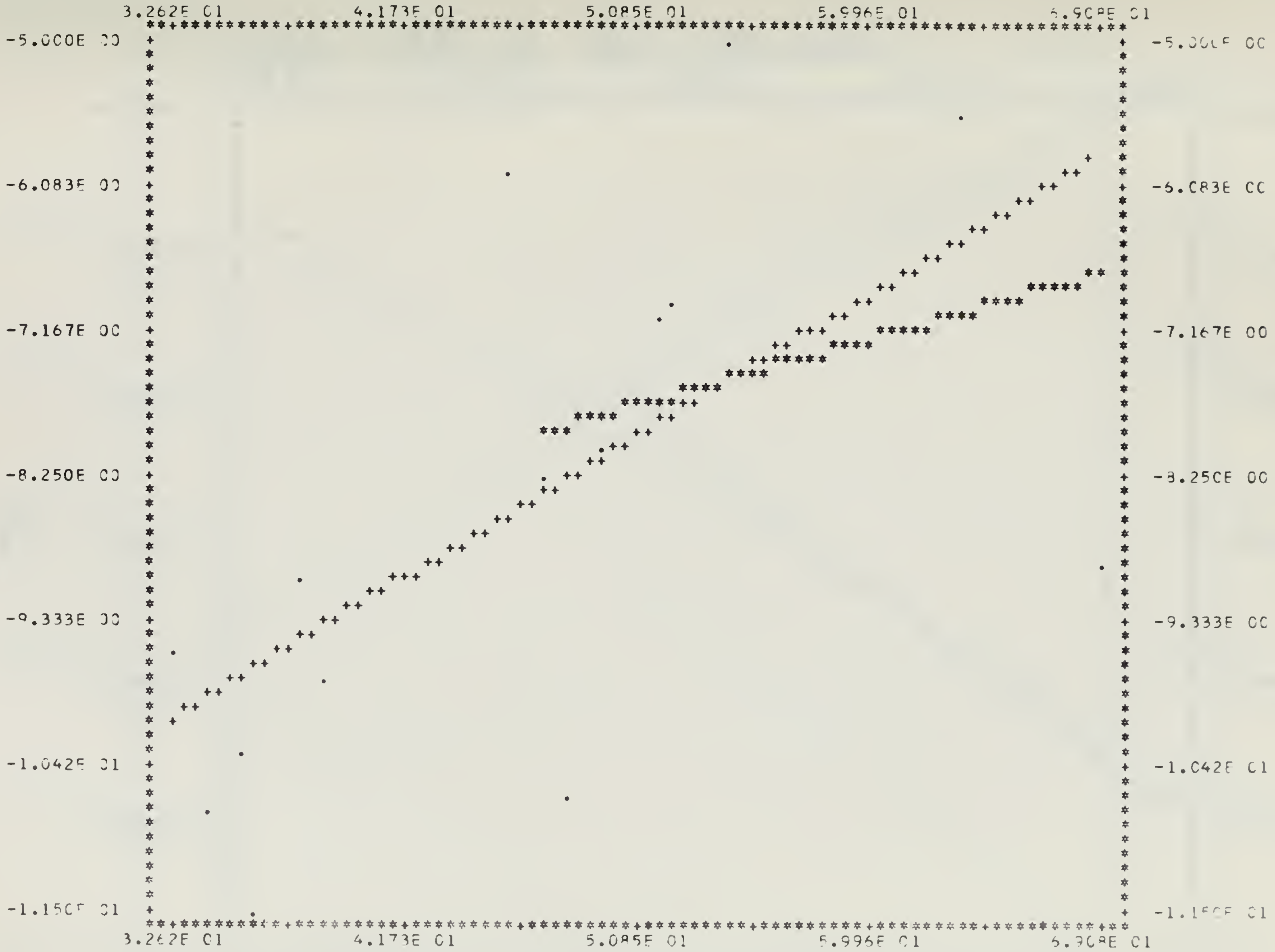
```
1932-1969     STD DEV  1.78      TREND   0.07313 FT PER YR
1947-1969     STD DEV  1.72      TREND  -0.10768 FT PER YR
```

GRID POINT 4



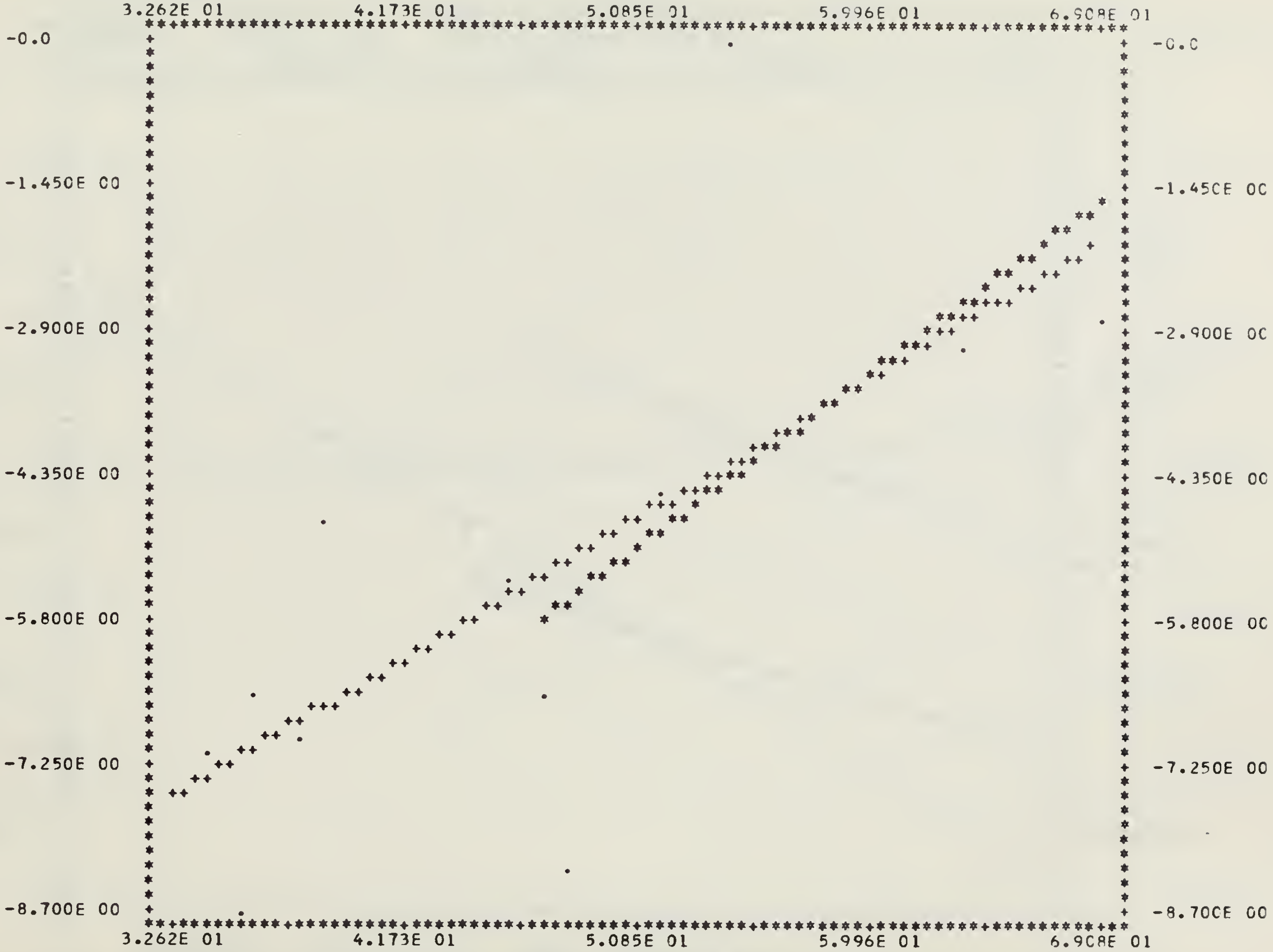
```
1932-1969     STD DEV  1.96     TREND    0.01209 FT PER YR
1947-1969     STD DEV  2.30     TREND   -0.08559 FT PER YR
```

GRID POINT 5



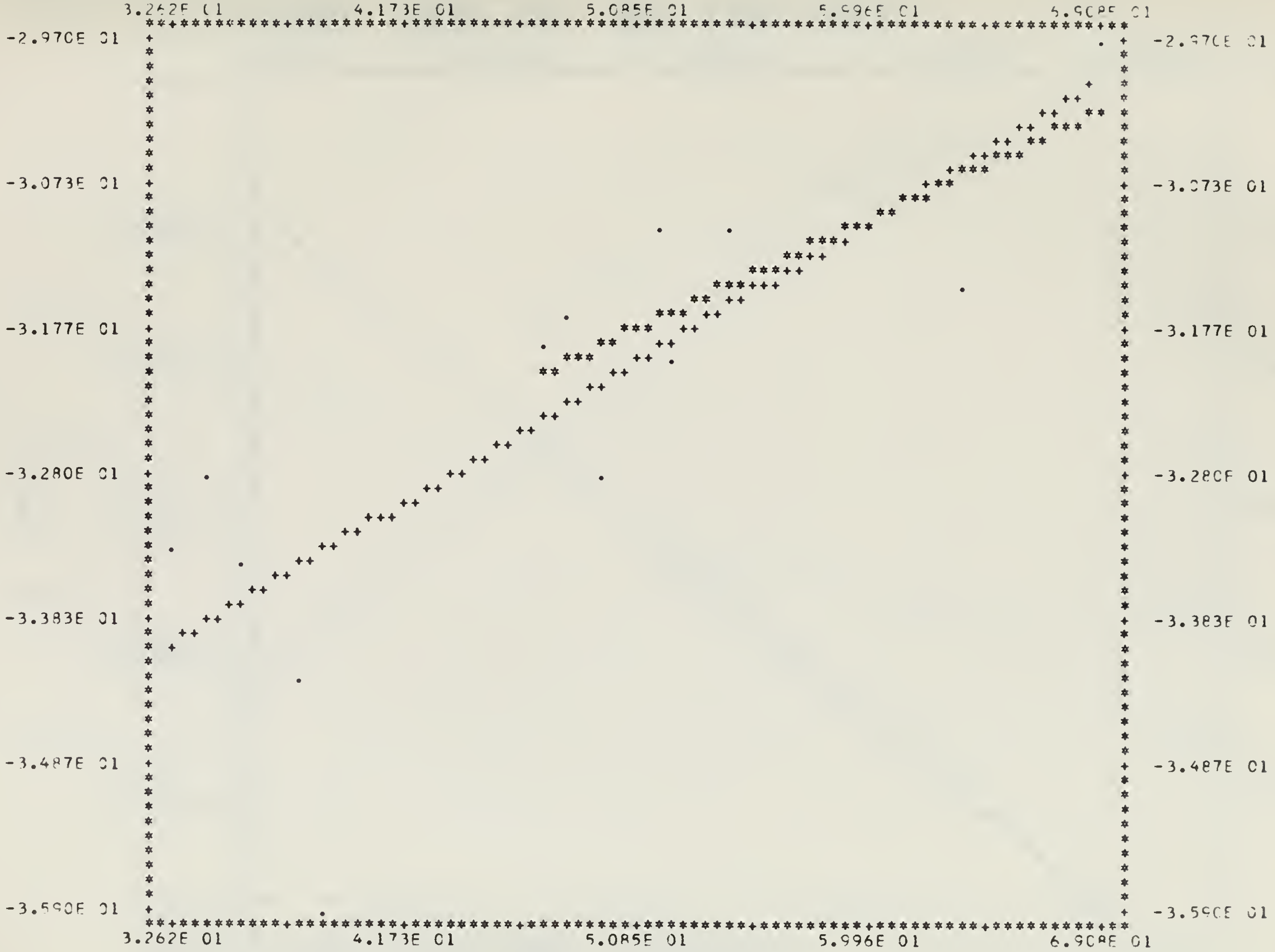
```
1932-1969      STD DEV  1.57       TREND   0.11544 FT PER YR
1947-1969      STD DEV  1.76       TREND   0.05399 FT PER YR
```

GRID POINT 6



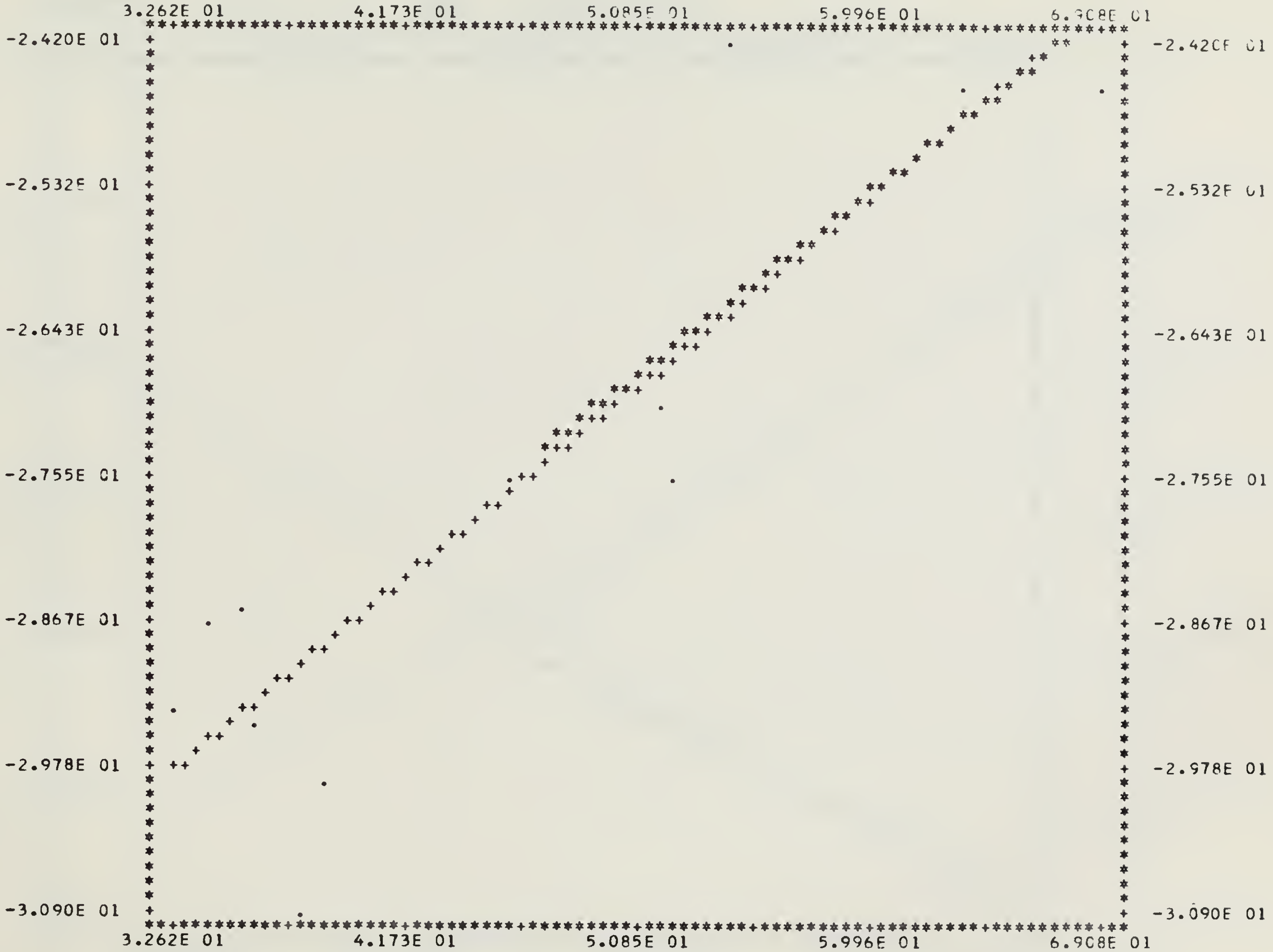
```
1932-1969     STD DEV  1.58     TREND   0.15366 FT PER YR
1947-1969     STD DEV  1.98     TREND   0.19059 FT PER YR
```

GRID POINT 7



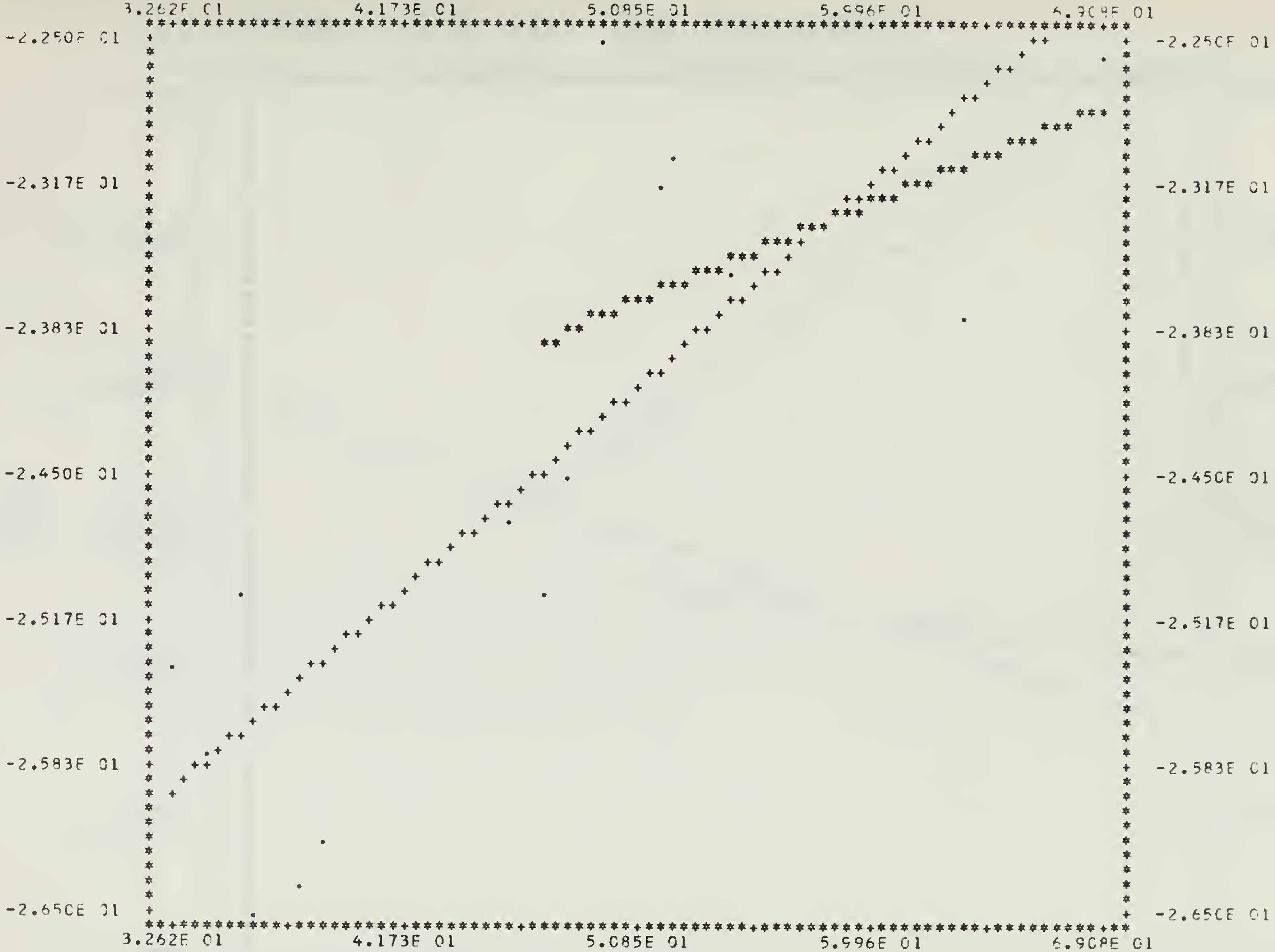
```
1932-1969     STD DEV  0.91     TREND   0.10998 FT PER YR
1947-1969     STD DEV  0.62     TREND   0.08582 FT PER YR
```

GRID PCINT 8



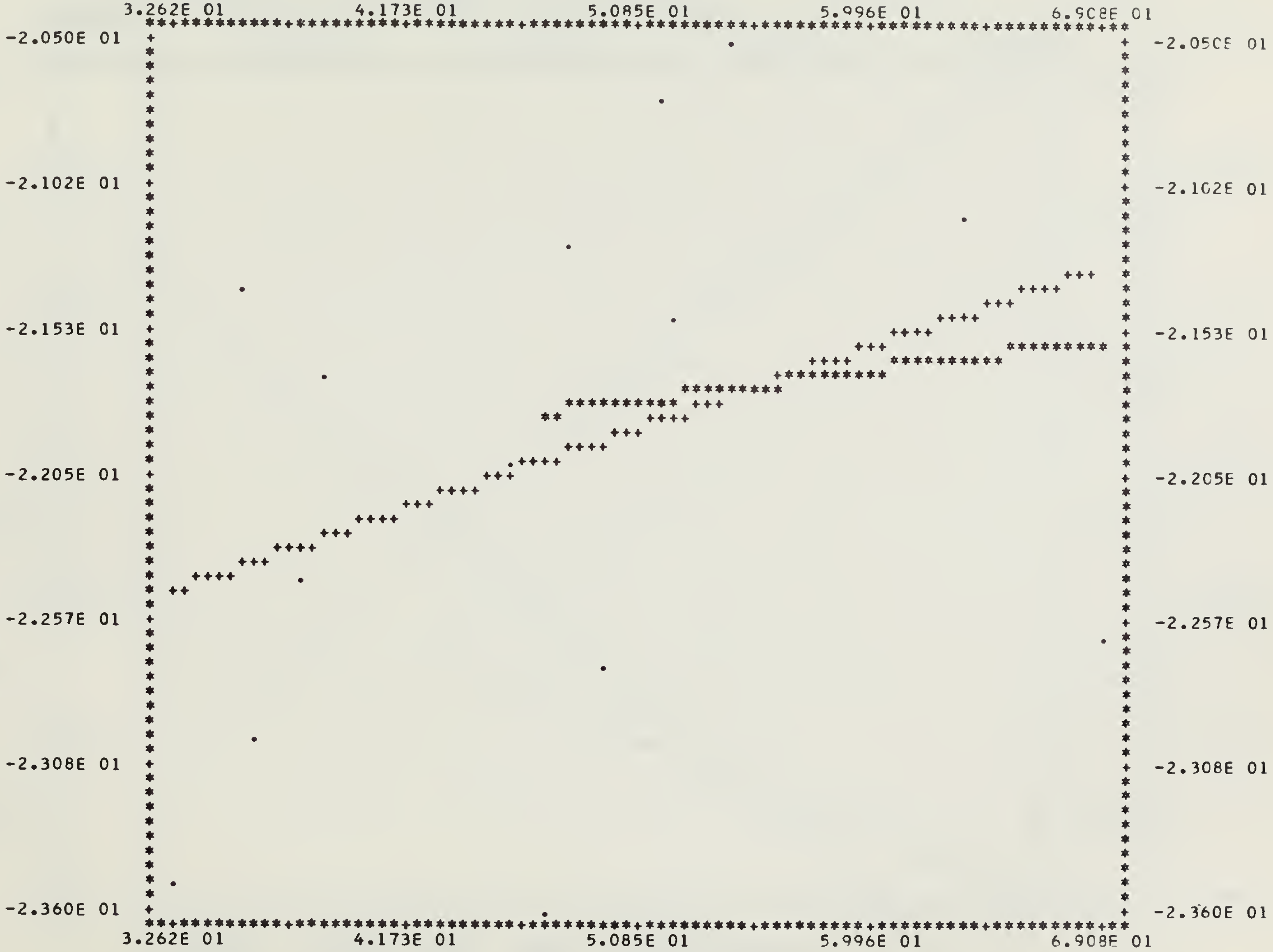
1932-1969 STD DEV 0.92 TREND 0.16231 FT PER YR
1947-1969 STD DEV 0.89 TREND 0.15298 FT PER YR

```
GRID PRINT     9
```



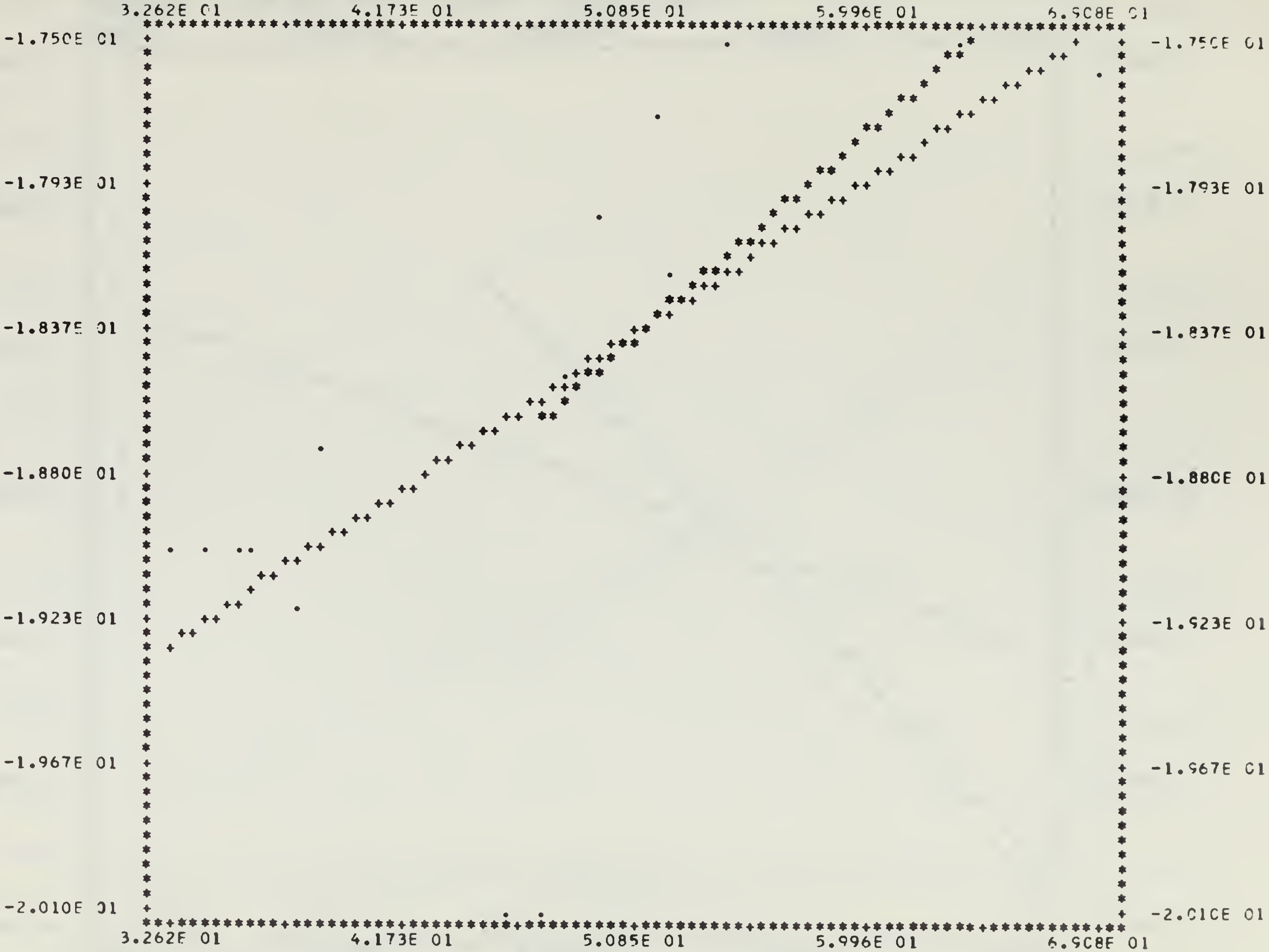
```
1932-1969     STD DEV   0.80     TREND    0.10185 FT PER YR
1947-1969     STD DEV   0.80     TREND    0.04905 FT PER YR
```

GRID POINT 10



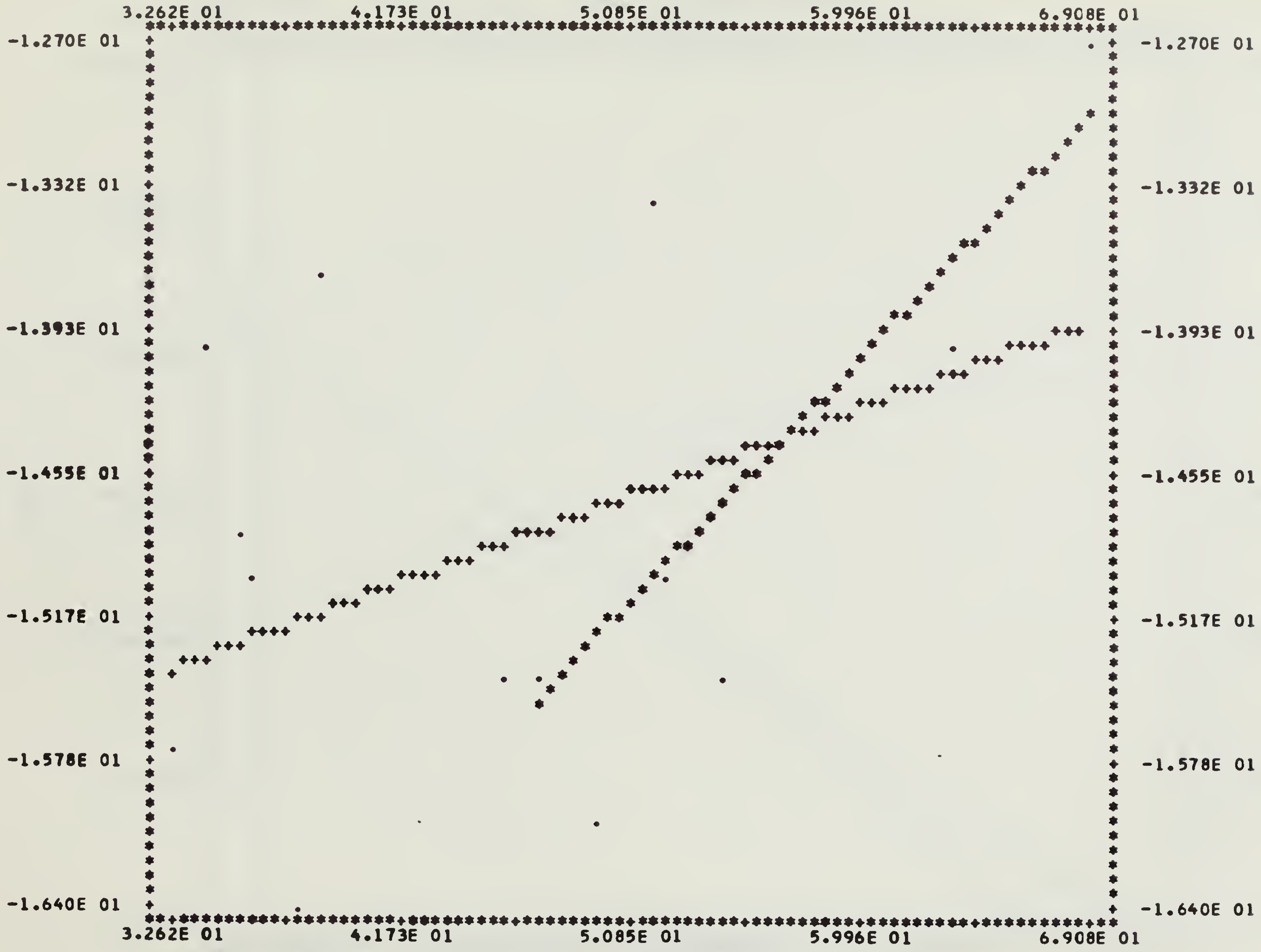
```
1932-1969     STD DEV  0.90     TREND    0.03193 FT PER YR
1947-1969     STD DEV  1.10     TREND    0.01214 FT PER YR
```

GRID POINT 11



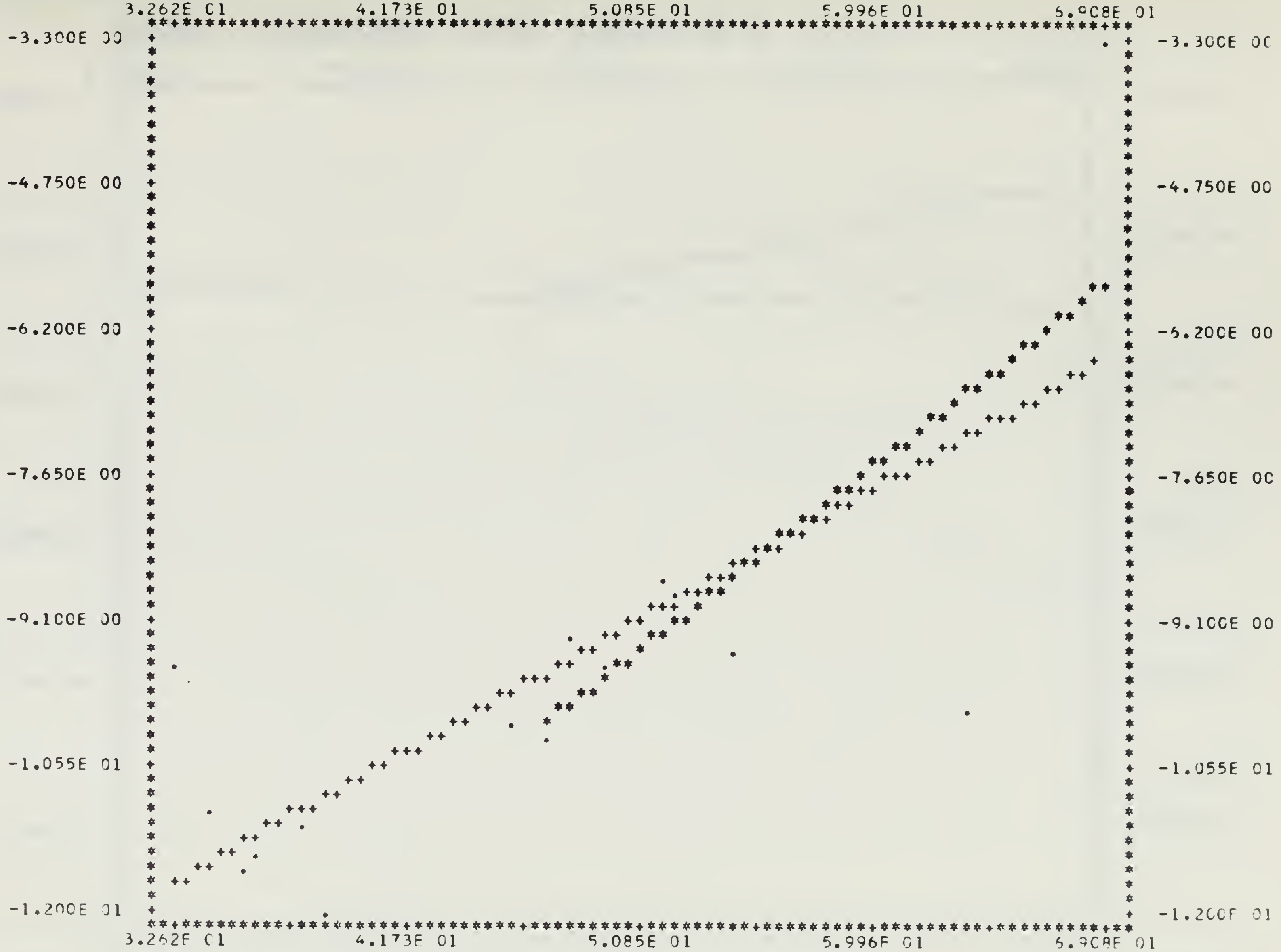
1932-1969 STD DEV 0.65 TREND 0.05097 FT PER YR
1947-1969 STD DEV 0.69 TREND 0.06726 FT PER YR

GRID POINT 12



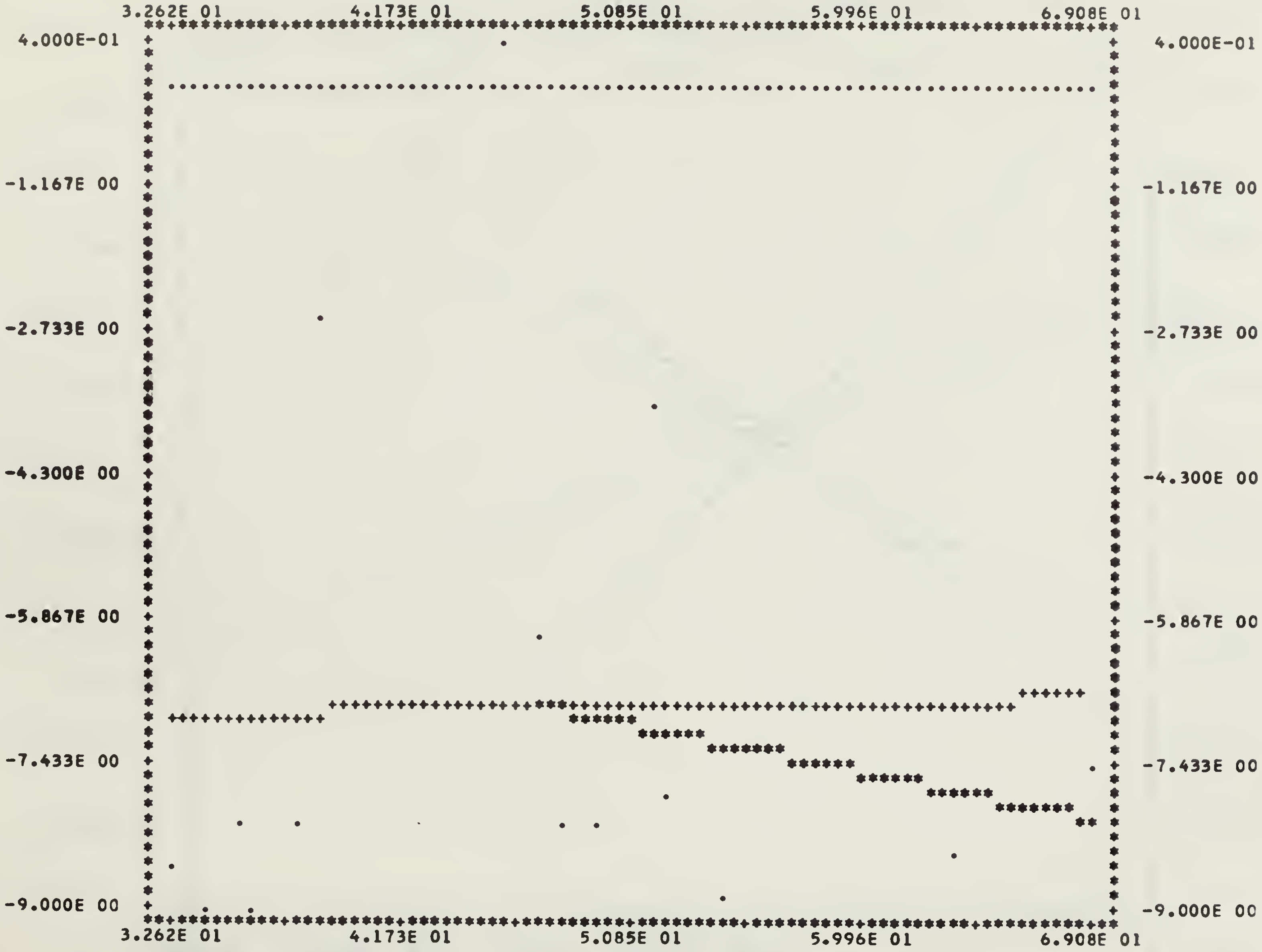
```
1932-1969      STD DEV  0.94      TREND    0.04093 FT PER YR
1947-1969      STD DEV  0.74      TREND    0.11375 FT PER YR
```

GRID POINT 13



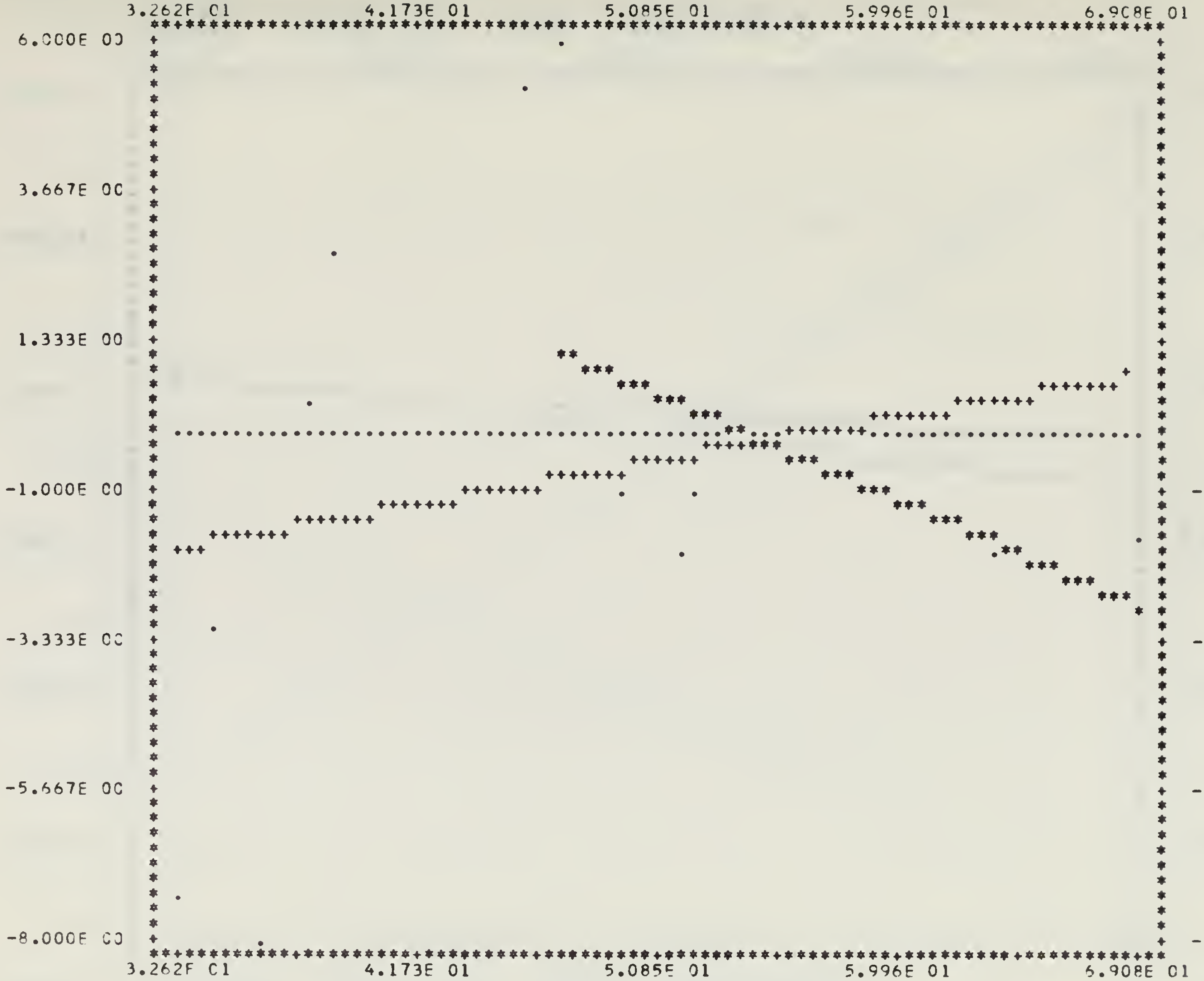
```
1932-1969      STD DEV  1.32      TREND   0.14333 FT PER YR
1947-1969      STD DEV  1.55      TREND   0.20030 FT PER YR
```

GRID POINT 14



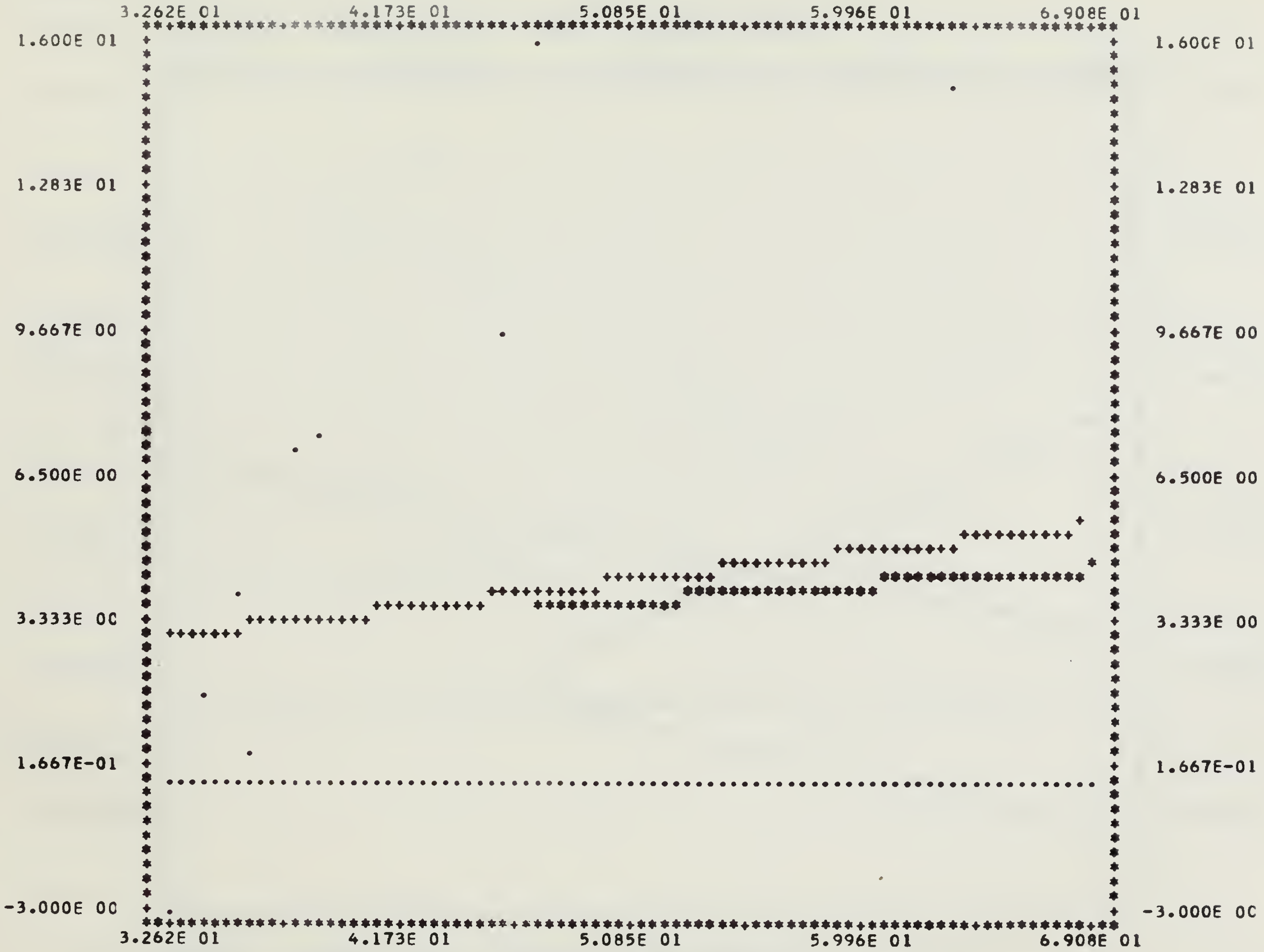
```
1932-1969     STD DEV  2.78      TREND    0.00572 FT PER YR
1947-1969     STD DEV  1.67      TREND   -0.05465 FT PER YR
```

GRID POINT 15



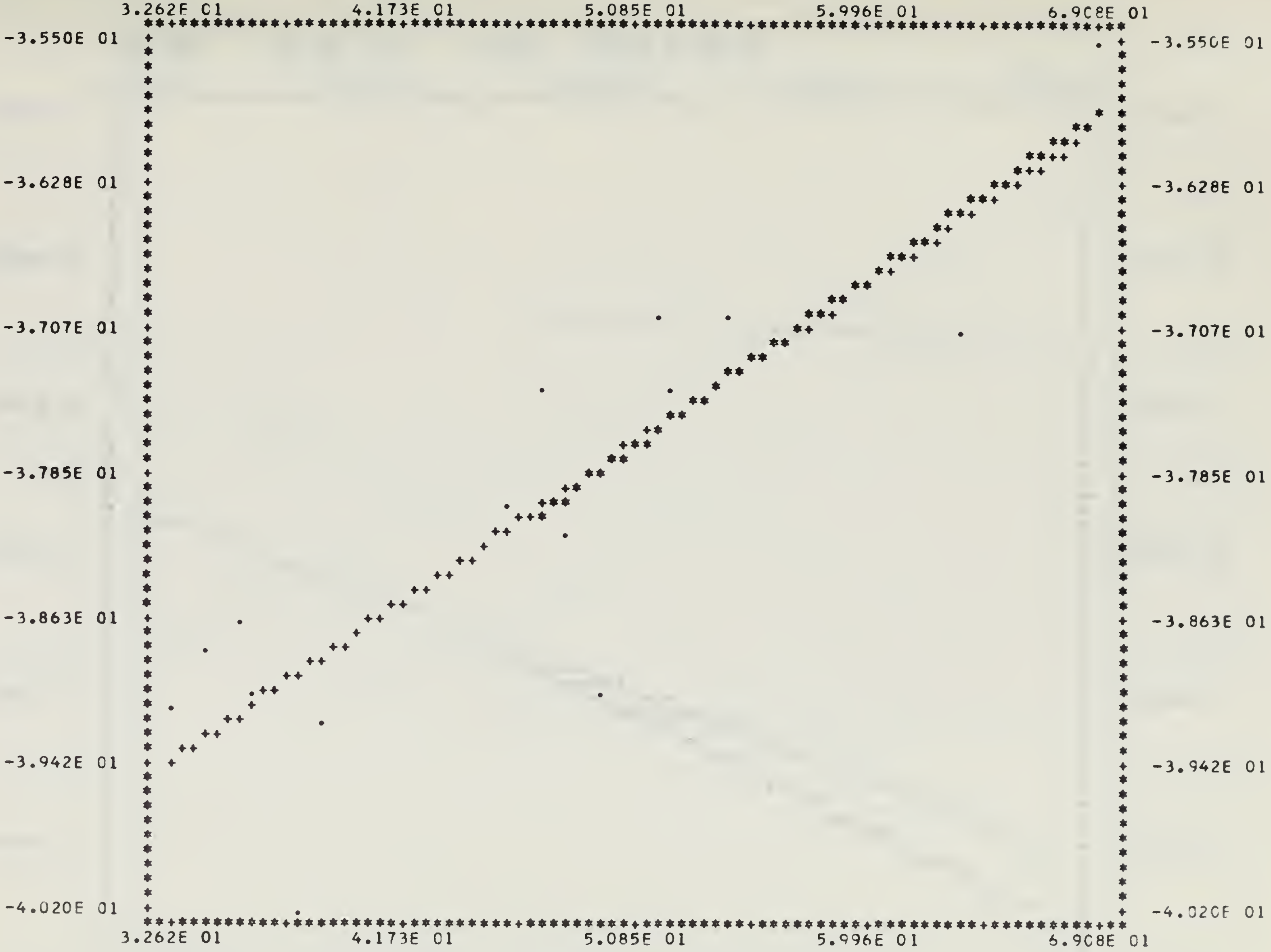
```
1932-1969     STD DEV  3.73     TREND   0.07459 FT PER YR
1947-1969     STD DEV  2.20     TREND  -0.17859 FT PER YR
```

GRID POINT 16



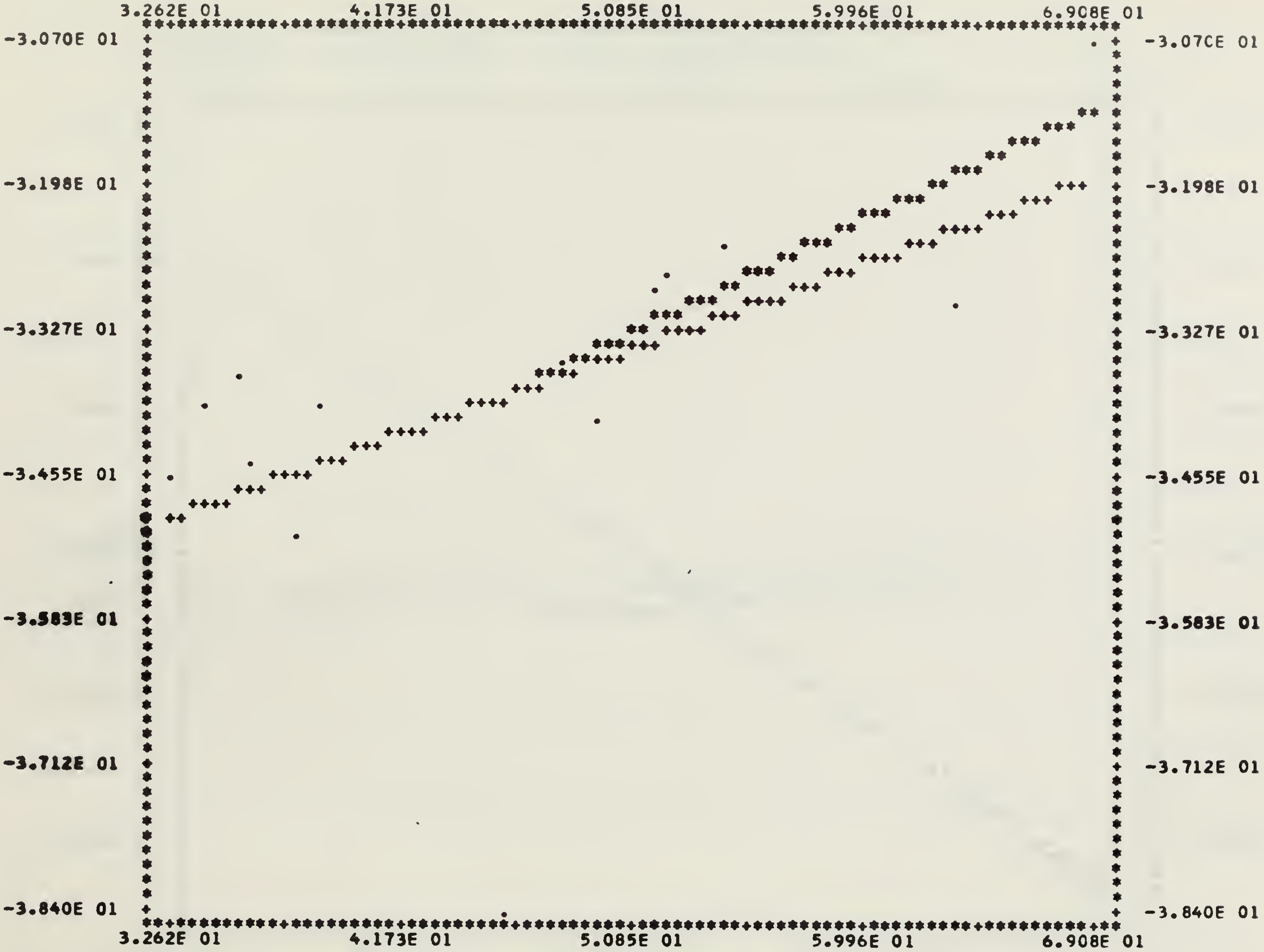
```
1932-1969     STD DEV  5.80     TREND    0.06808 FT PER YR
1947-1969     STD DEV  7.17     TREND    0.04036 FT PER YR
```

GRID POINT 17



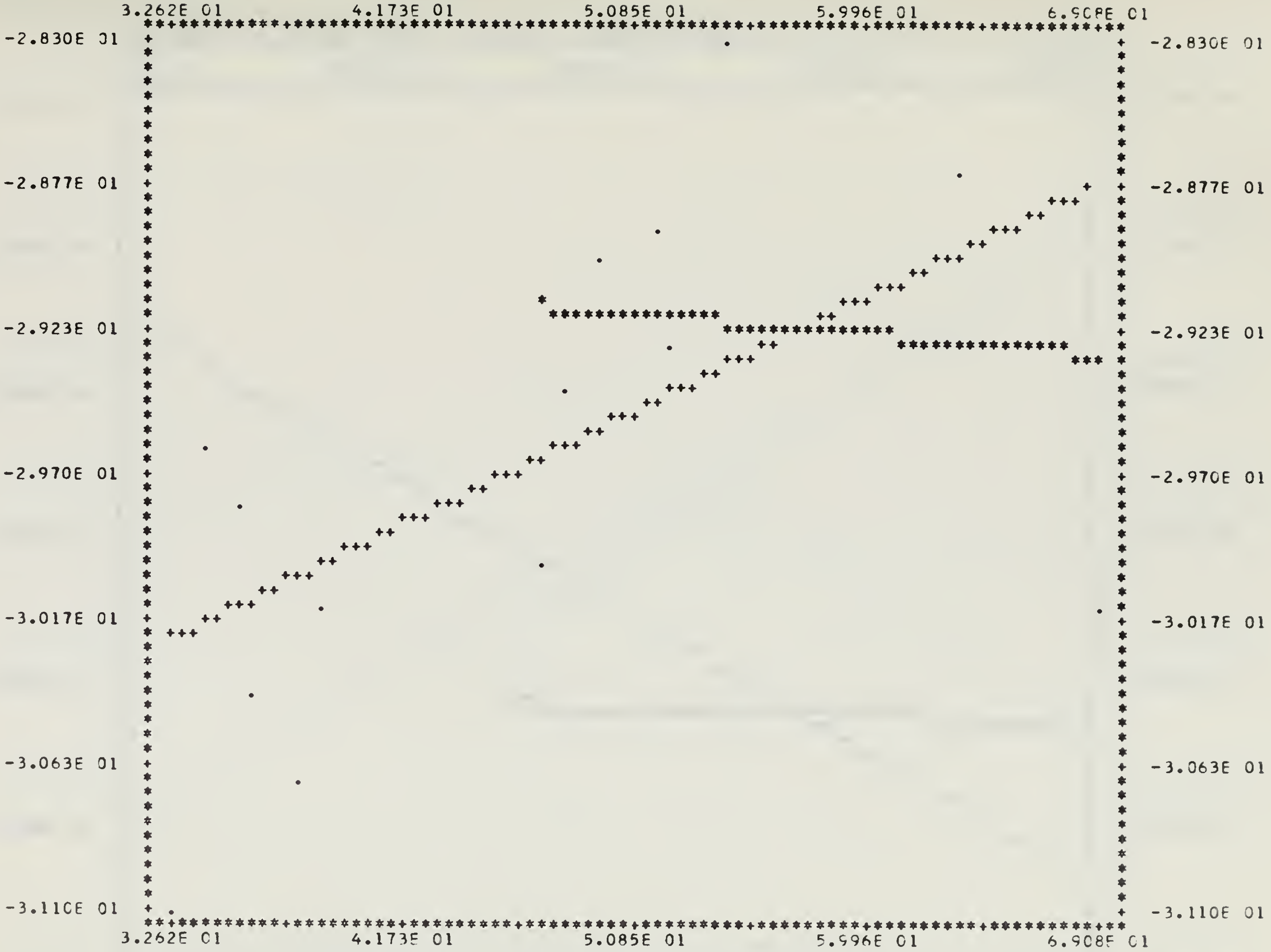
1932-1969 STD DEV 0.61 TREND 0.09448 FT PER YR
1947-1969 STD DEV 0.65 TREND 0.09928 FT PER YR

GRID POINT 18



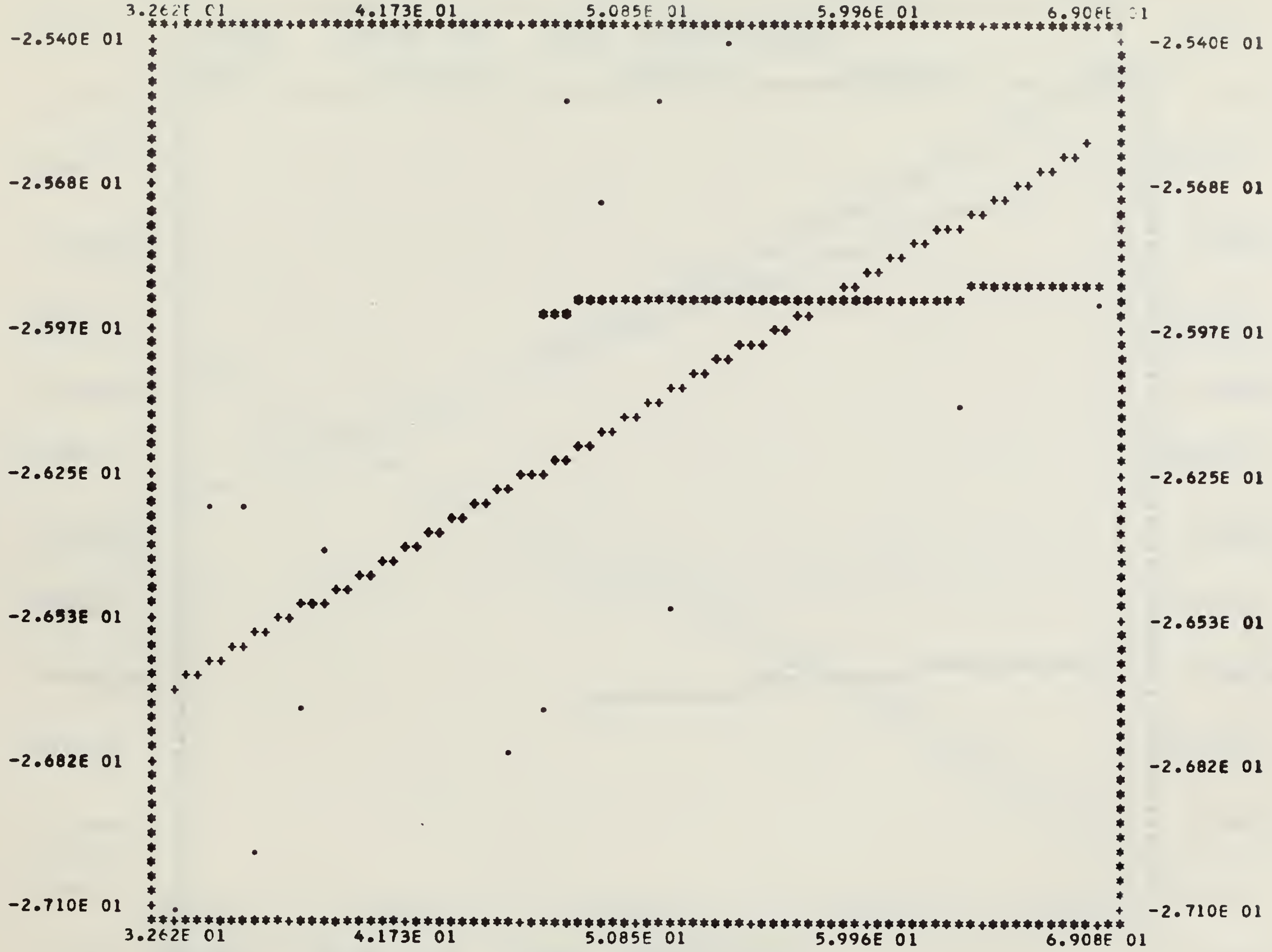
1932-1969 STD DEV 1.37 TREND 0.08245 FT PER YR
1947-1969 STD DEV 0.57 TREND 0.10934 FT PER YR

GRID POINT 19



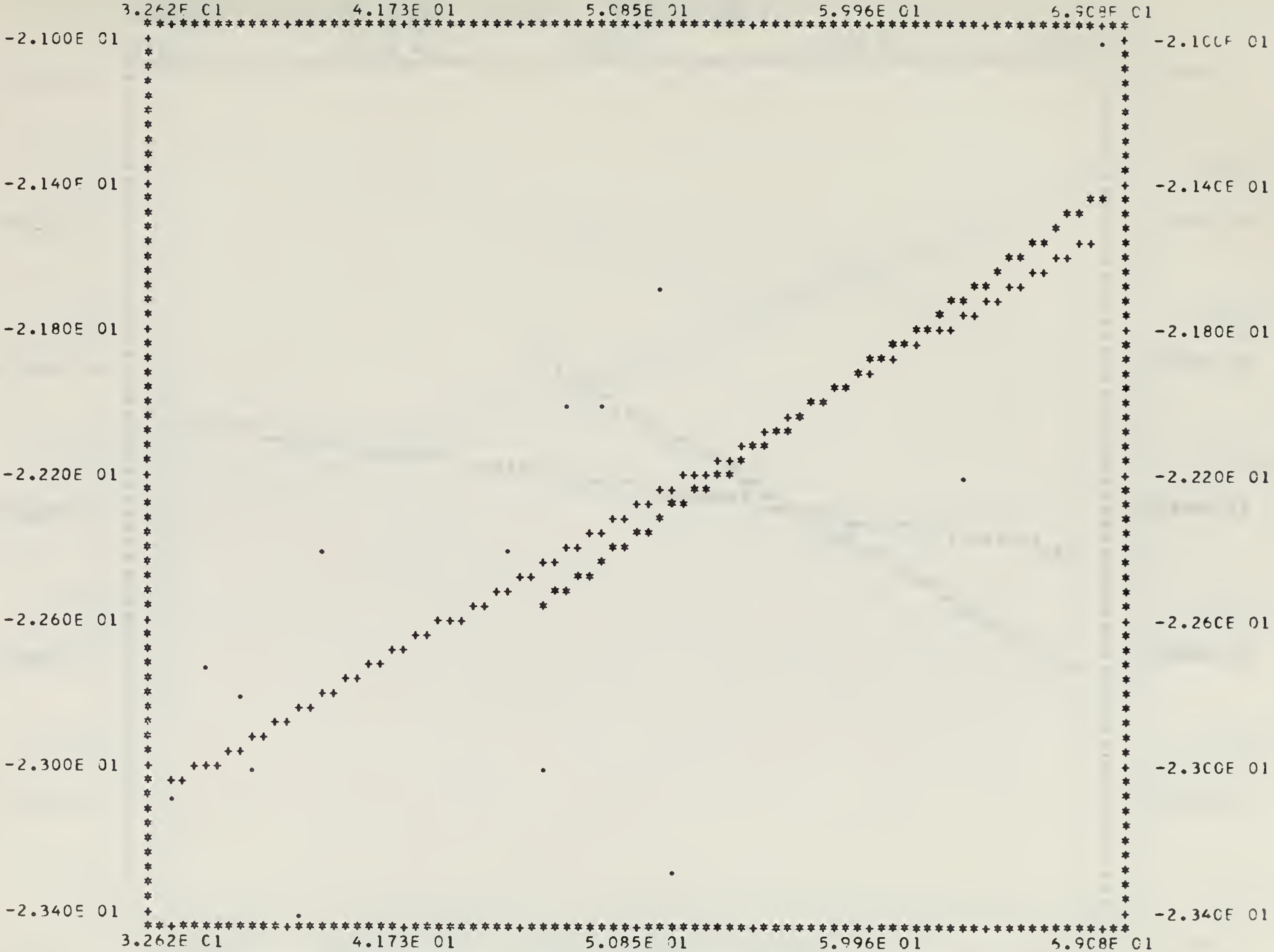
```
1932-1969     STD DEV  0.63     TREND   0.04041 FT PER YR
1947-1969     STD DEV  0.62     TREND  -0.00677 FT PER YR
```

GRID POINT 20



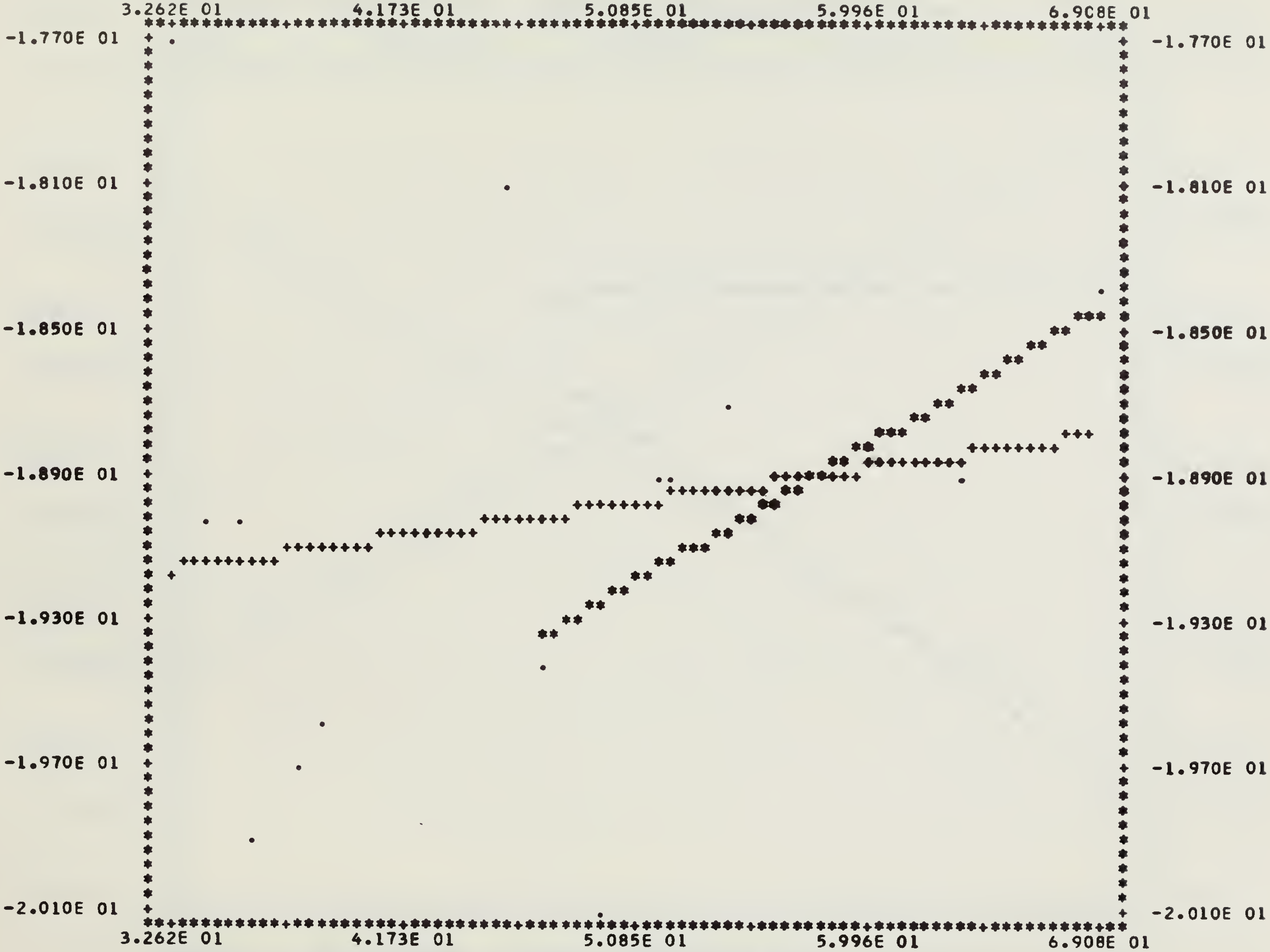
```
1932-1969      STD DEV  0.46      TREND    0.02941 FT PER YR
1947-1969      STD DEV  0.49      TREND    0.00182 FT PER YR
```

GRID POINT 21



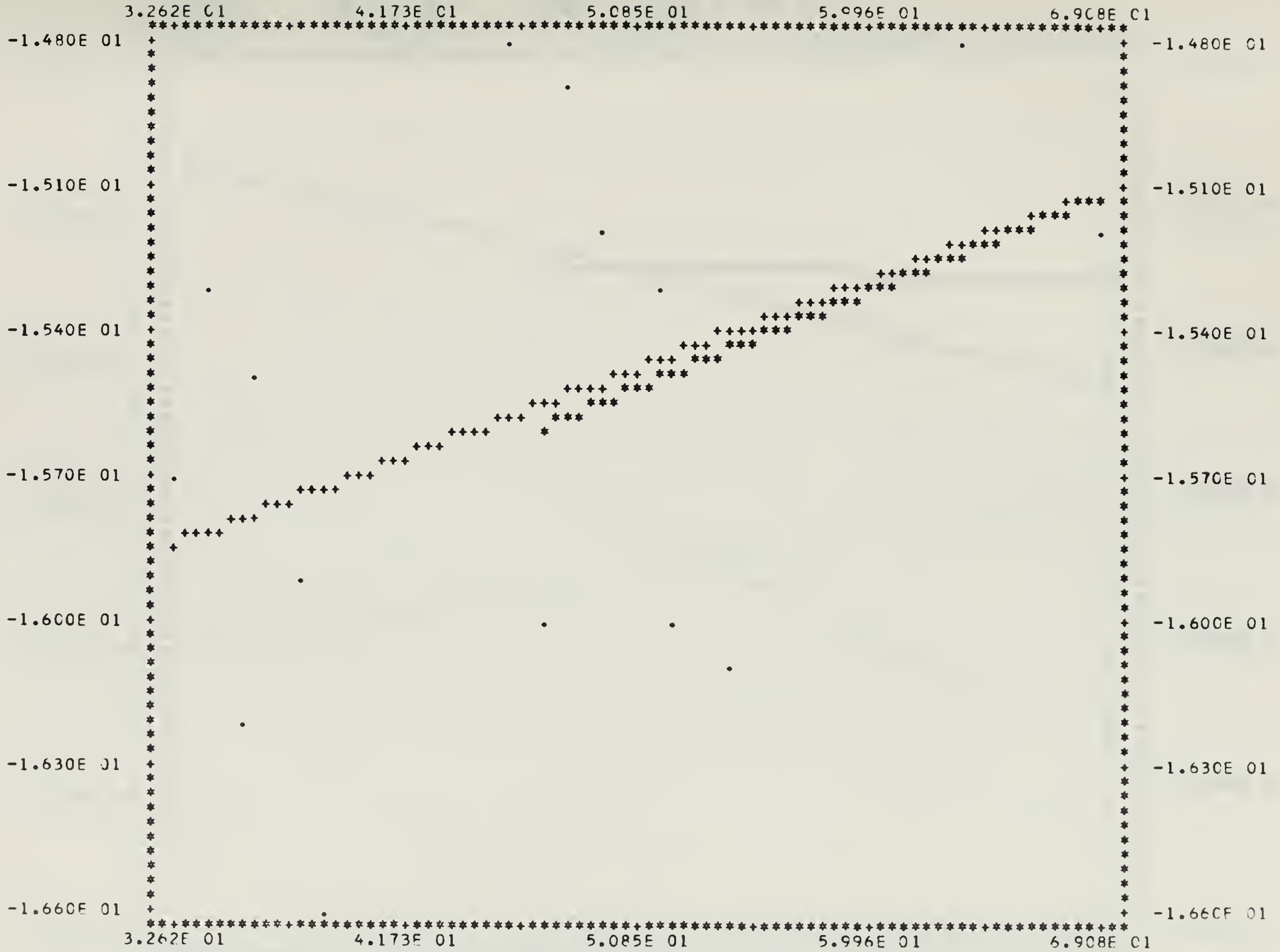
```
1932-1969     STD DEV  0.47      TREND    0.04181 FT PER YR
1947-1969     STD DEV  0.59      TREND    0.05161 FT PER YR
```

GRID POINT 22



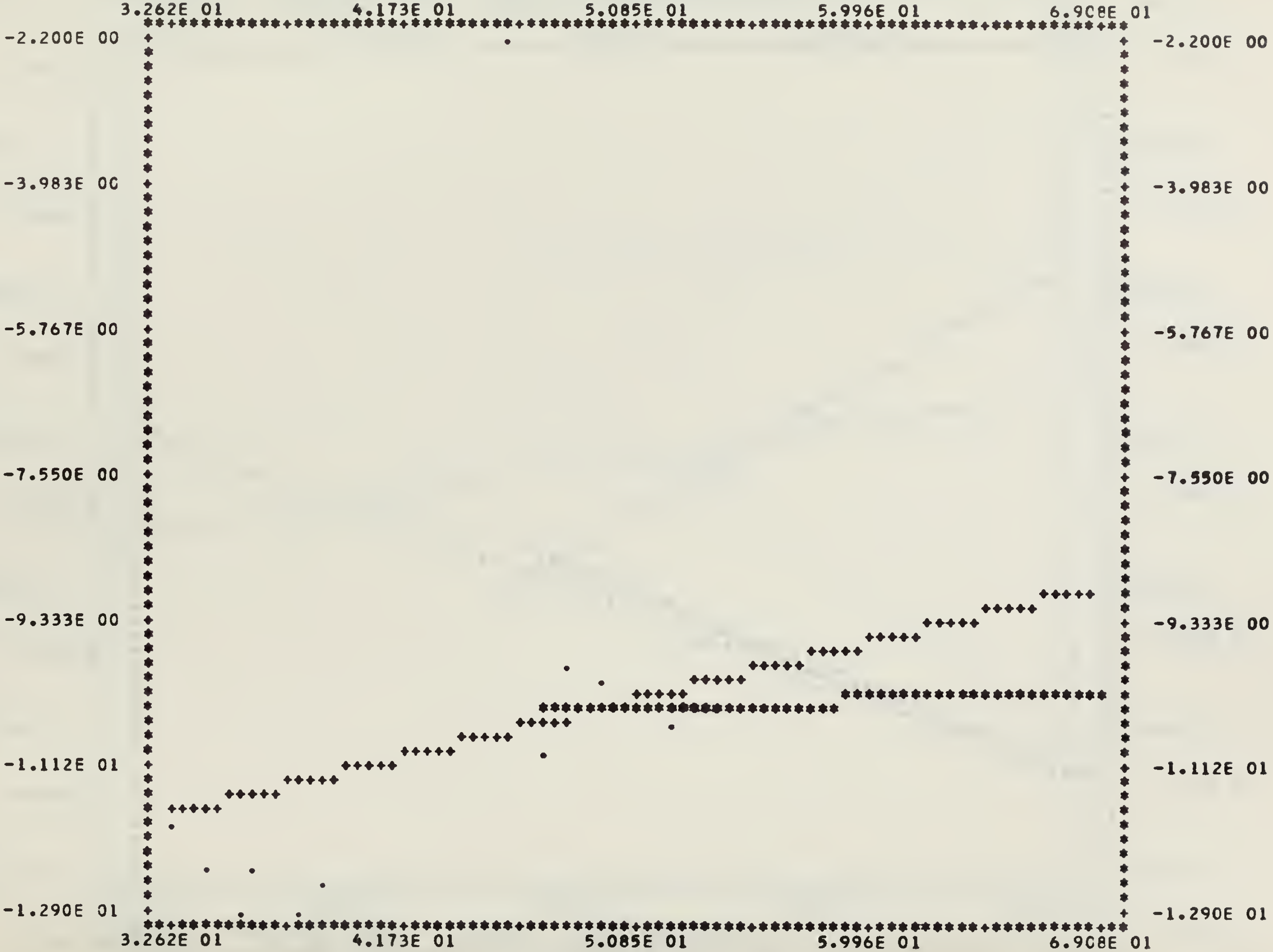
```
1932-1969     STD DEV  0.64     TREND    0.01043 FT PER YR
1947-1969     STD DEV  0.40     TREND    0.04133 FT PER YR
```

GRID POINT 23



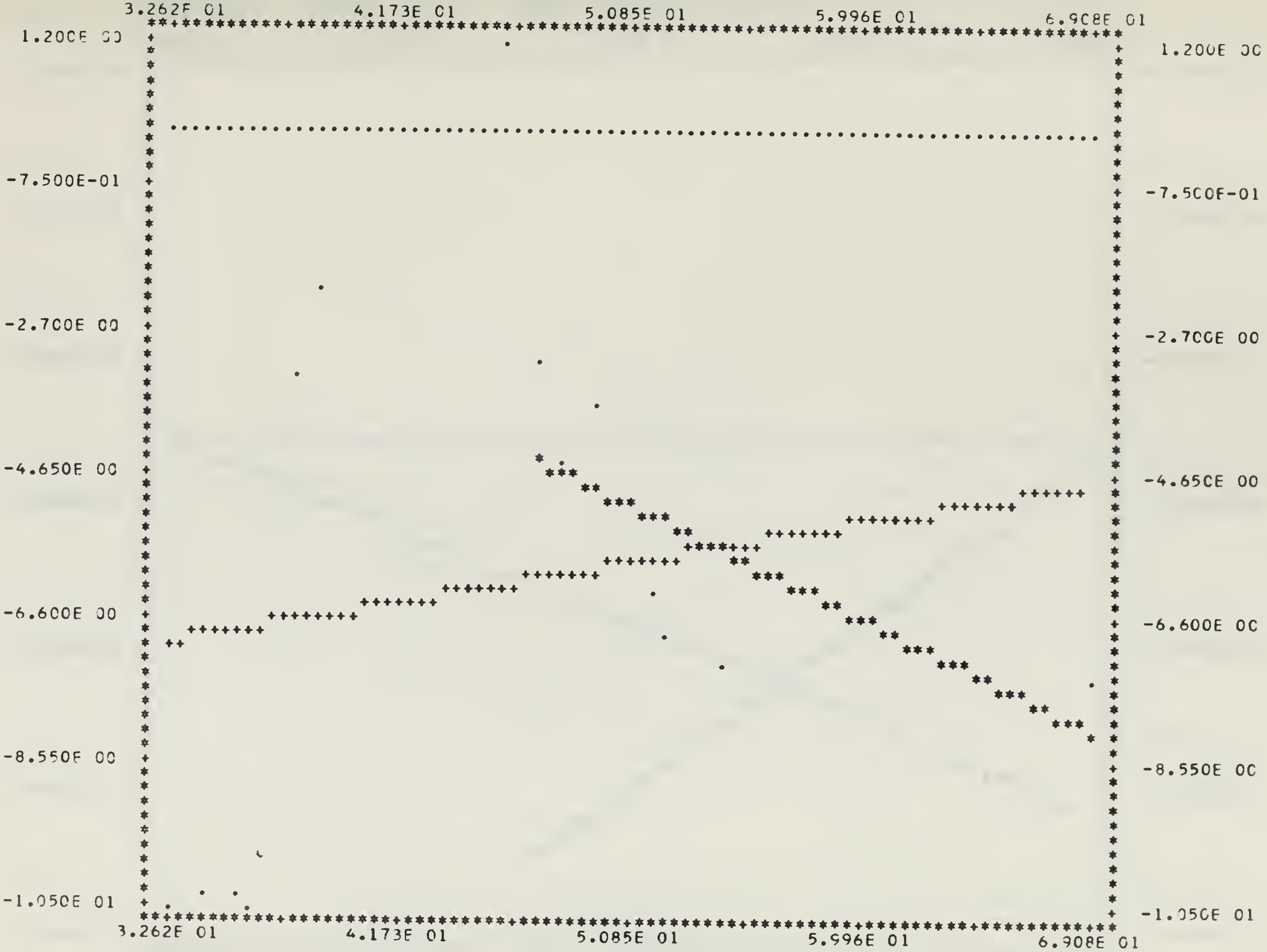
```
1932-1969     STD DEV  0.51     TREND   0.02005 FT PER YR
1947-1969     STD DEV  0.49     TREND   0.02229 FT PER YR
```

GRID POINT 24



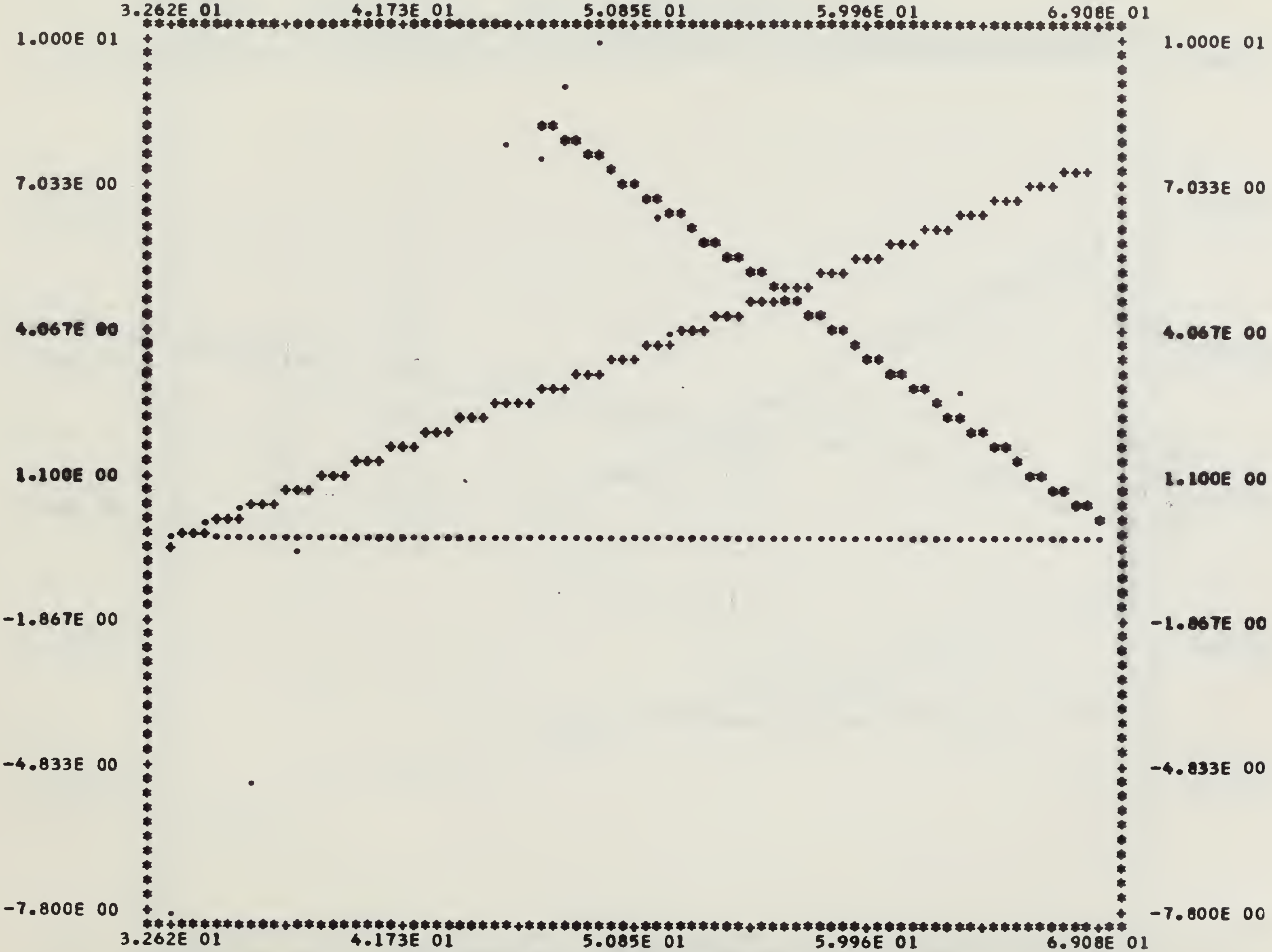
```
1932-1969     STD DEV  2.43       TREND    0.07837 FT PER YR
1947-1969     STD DEV  0.34       TREND    0.00263 FT PER YR
```

GRID POINT 25

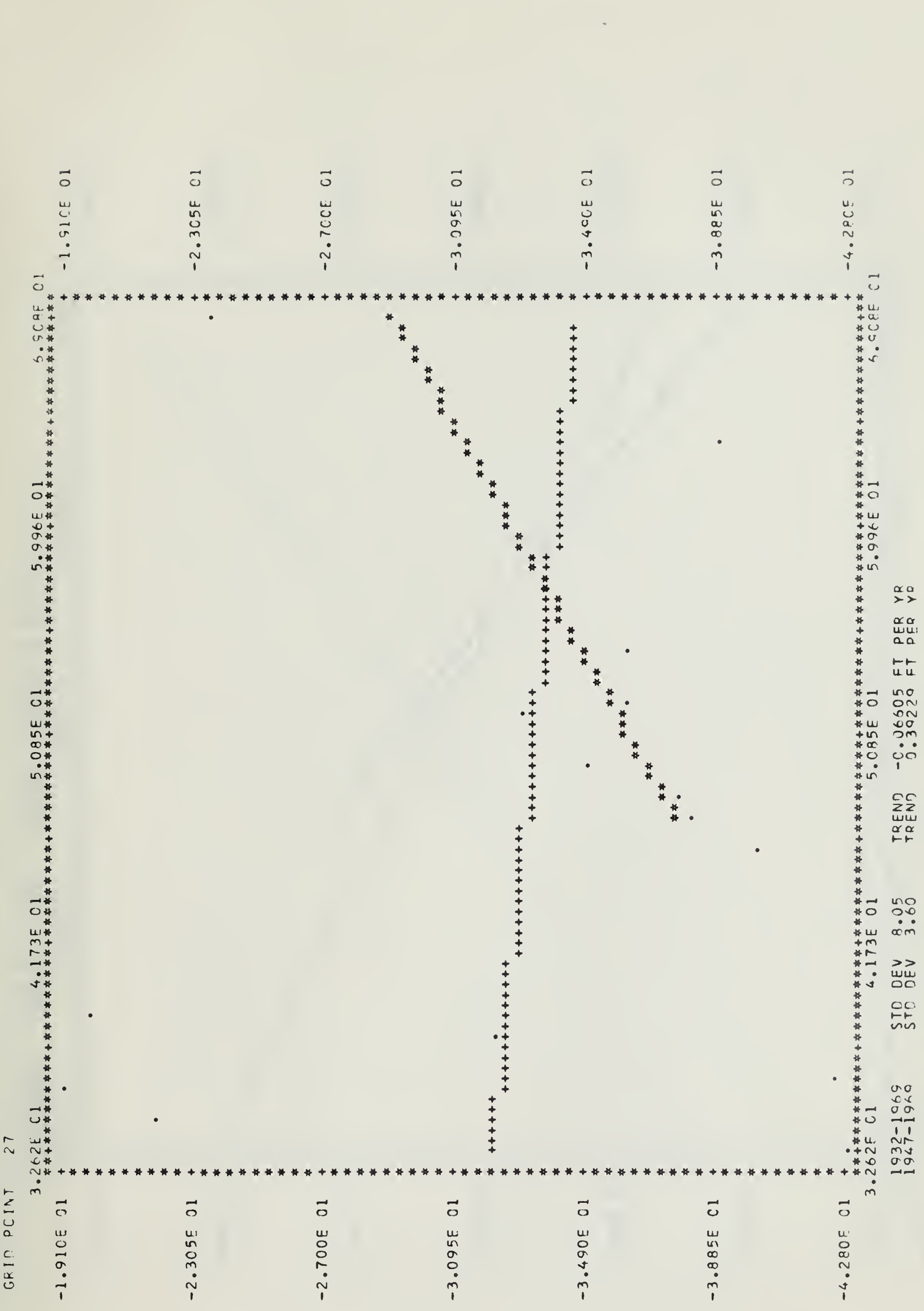


```
1932-1969     STD DEV  3.45     TREND   0.05982 FT PER YR
1947-1969     STD DEV  1.16     TREND  -0.16487 FT PER YR
```

GRID POINT   26

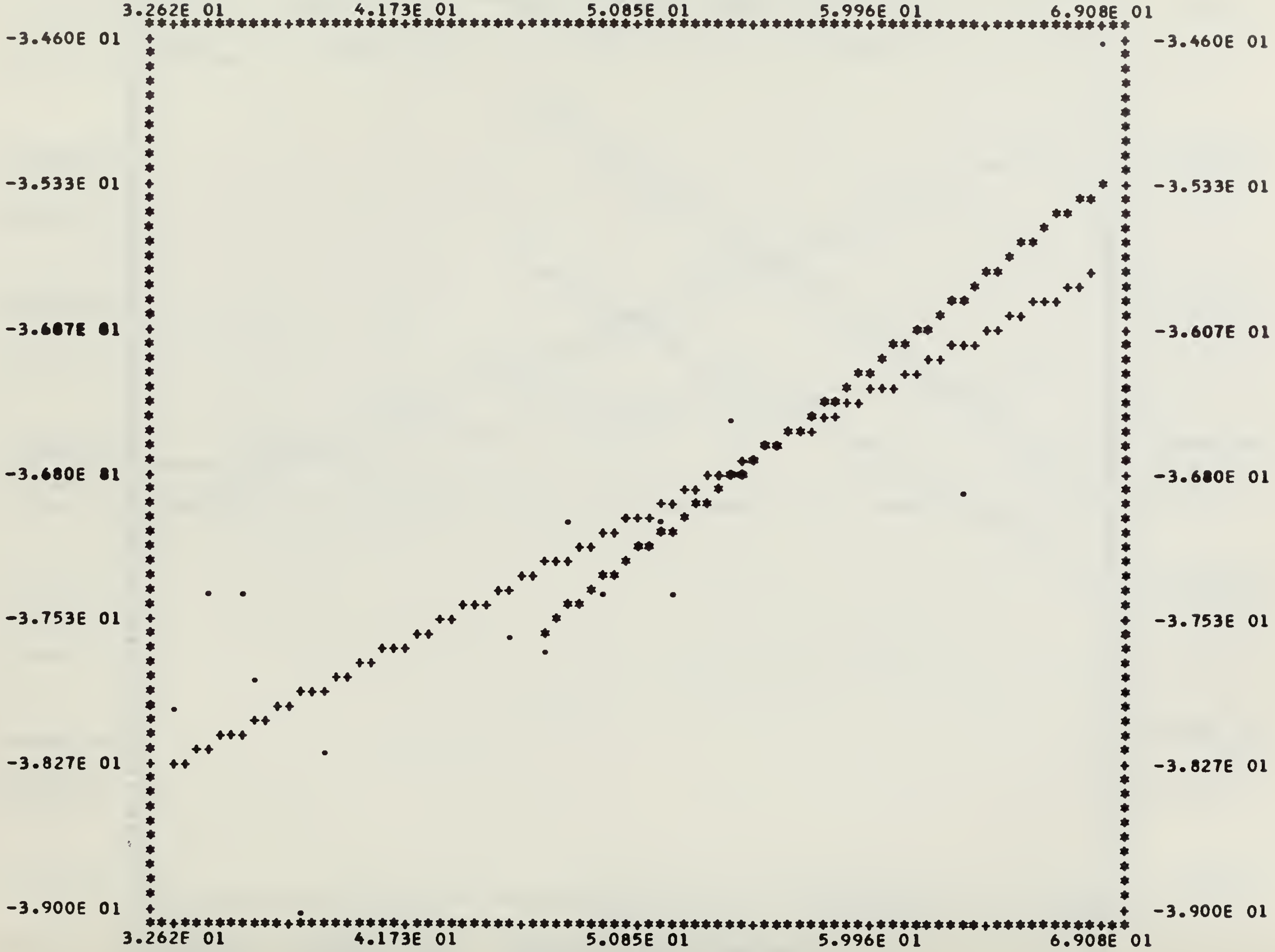


```
1932-1969     STD DEV  4.47     TREND   0.21370 FT PER YR
1947-1969     STD DEV  1.41     TREND  -0.37243 FT PER YR
```



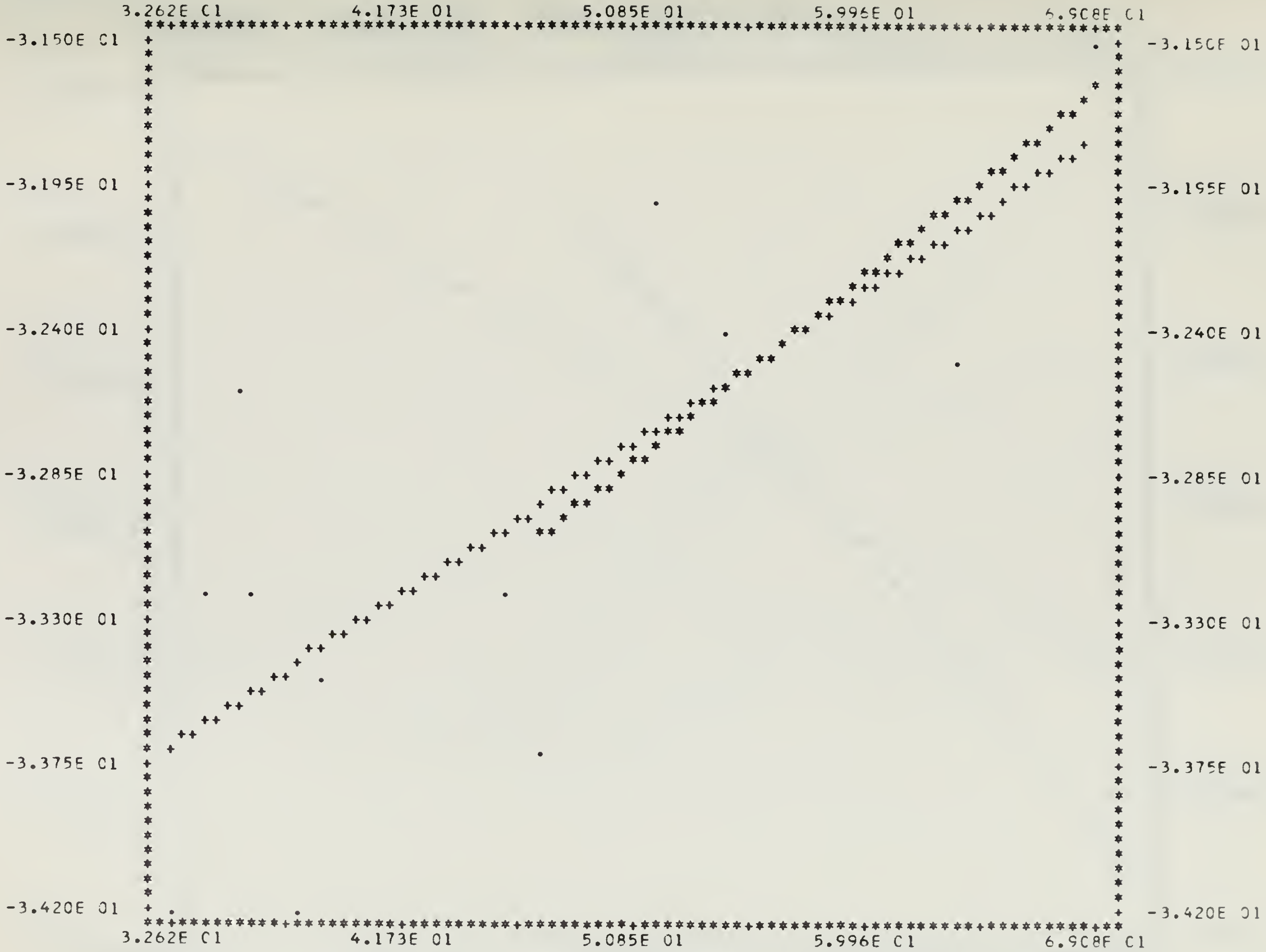
1932-1969 STD DEV 8.05 TREND -0.06605 FT PER YR
1947-1969 STD DEV 3.60 TREND 0.39229 FT PER YR

GRID POINT 28



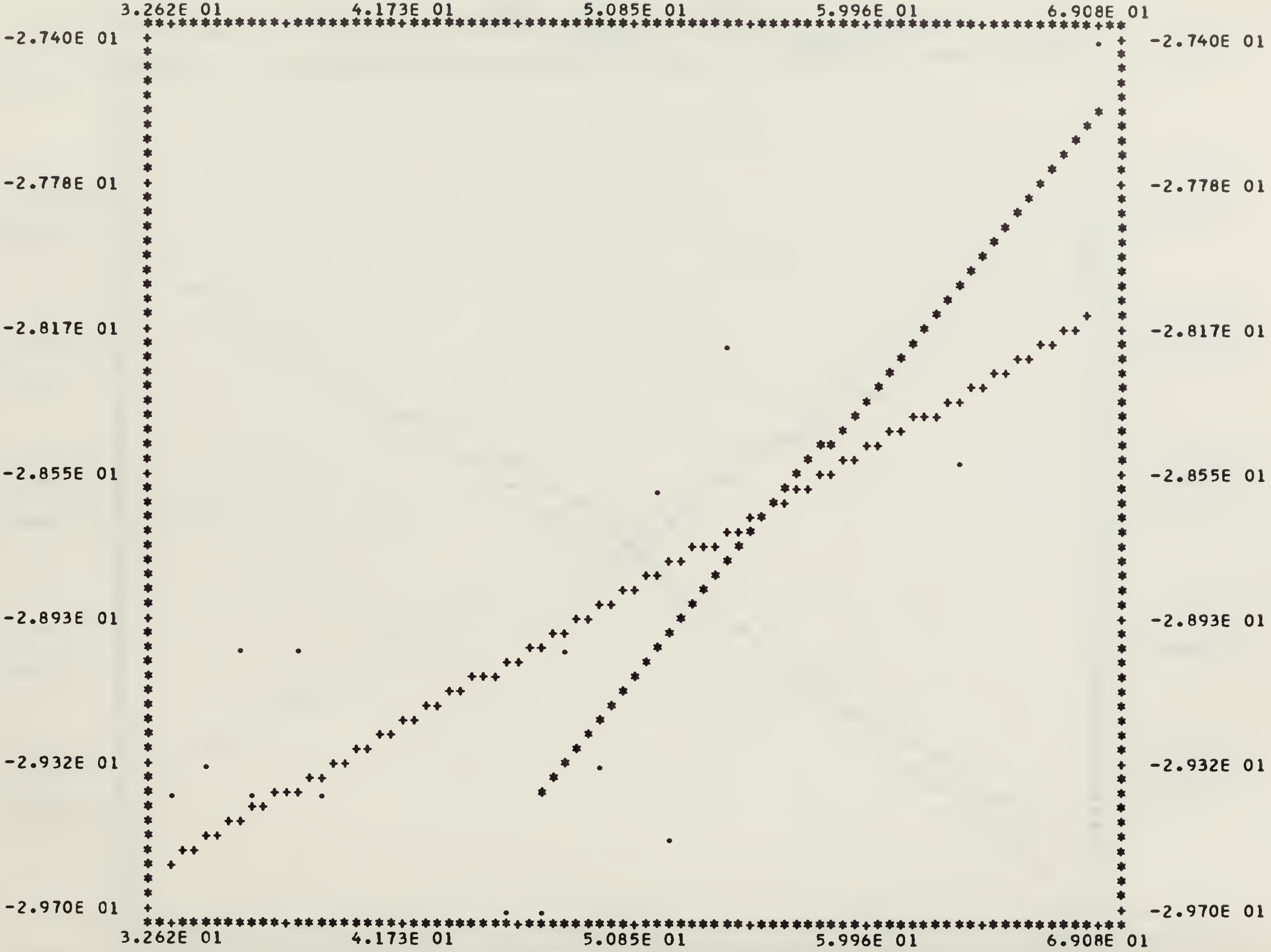
1932-1969 STD DEV 0.60 TREND 0.06916 FT PER YR
1947-1969 STD DEV 0.54 TREND 0.10269 FT PER YR

GRID POINT 29



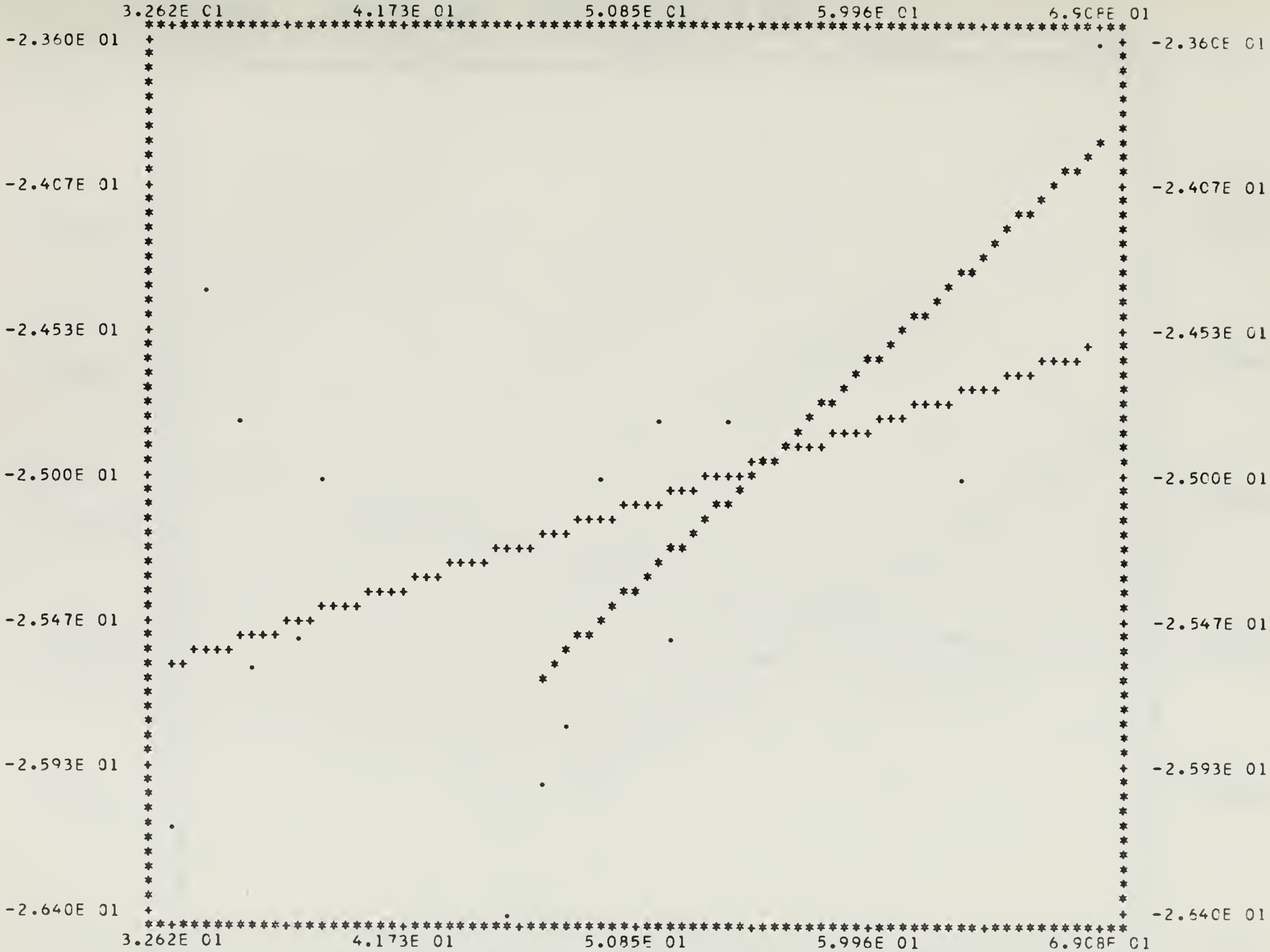
```
1932-1969     STD DEV  0.49     TREND   0.05178 FT PER YR
1947-1969     STD DEV  0.43     TREND   0.06360 FT PER YR
```

GRID PCINT 30



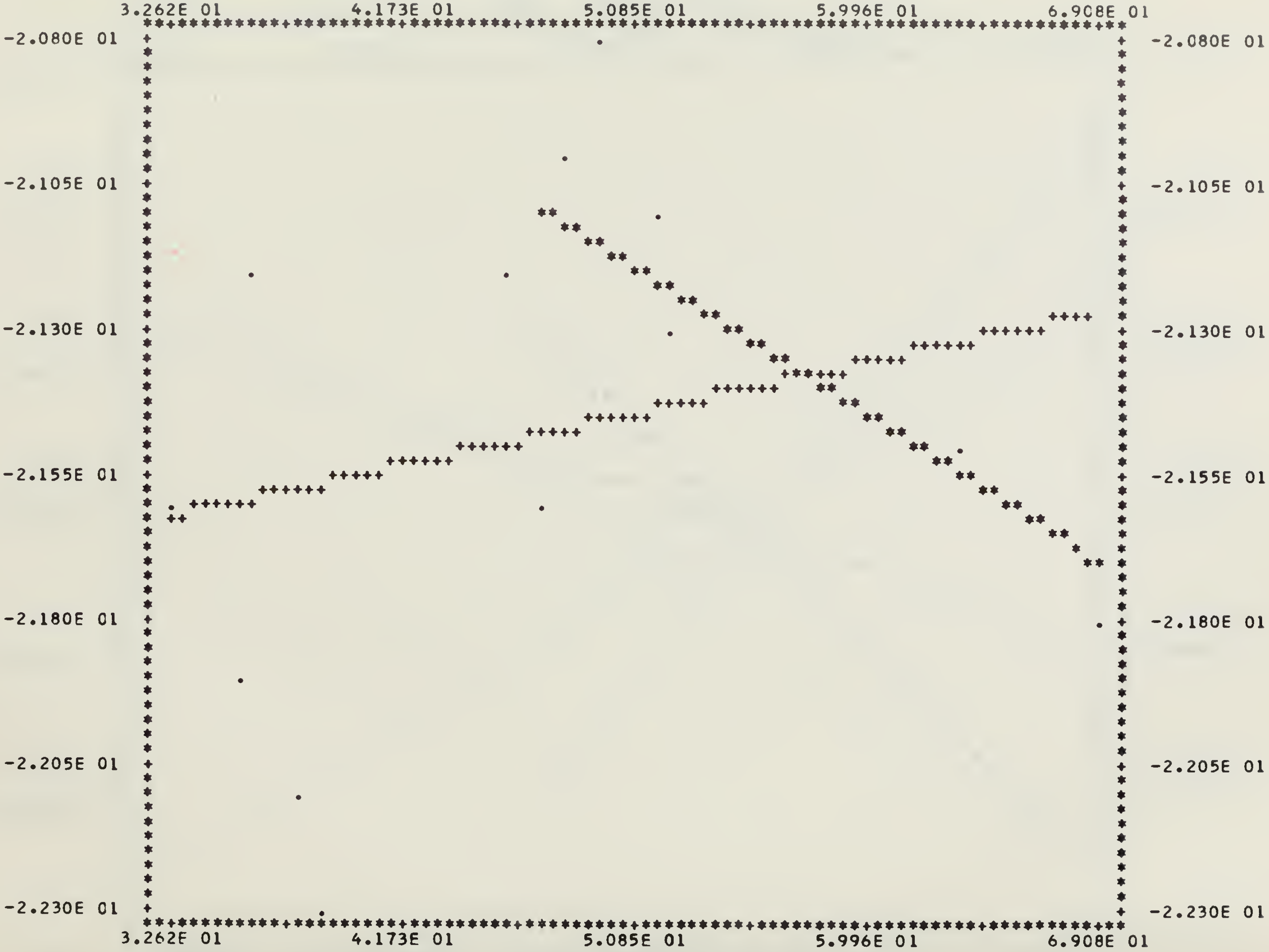
```
1932-1969     STD DEV  0.45      TREND    0.03977 FT PER YR
1947-1969     STD DEV  0.42      TREND    0.08076 FT PER YR
```

GRID POINT 31



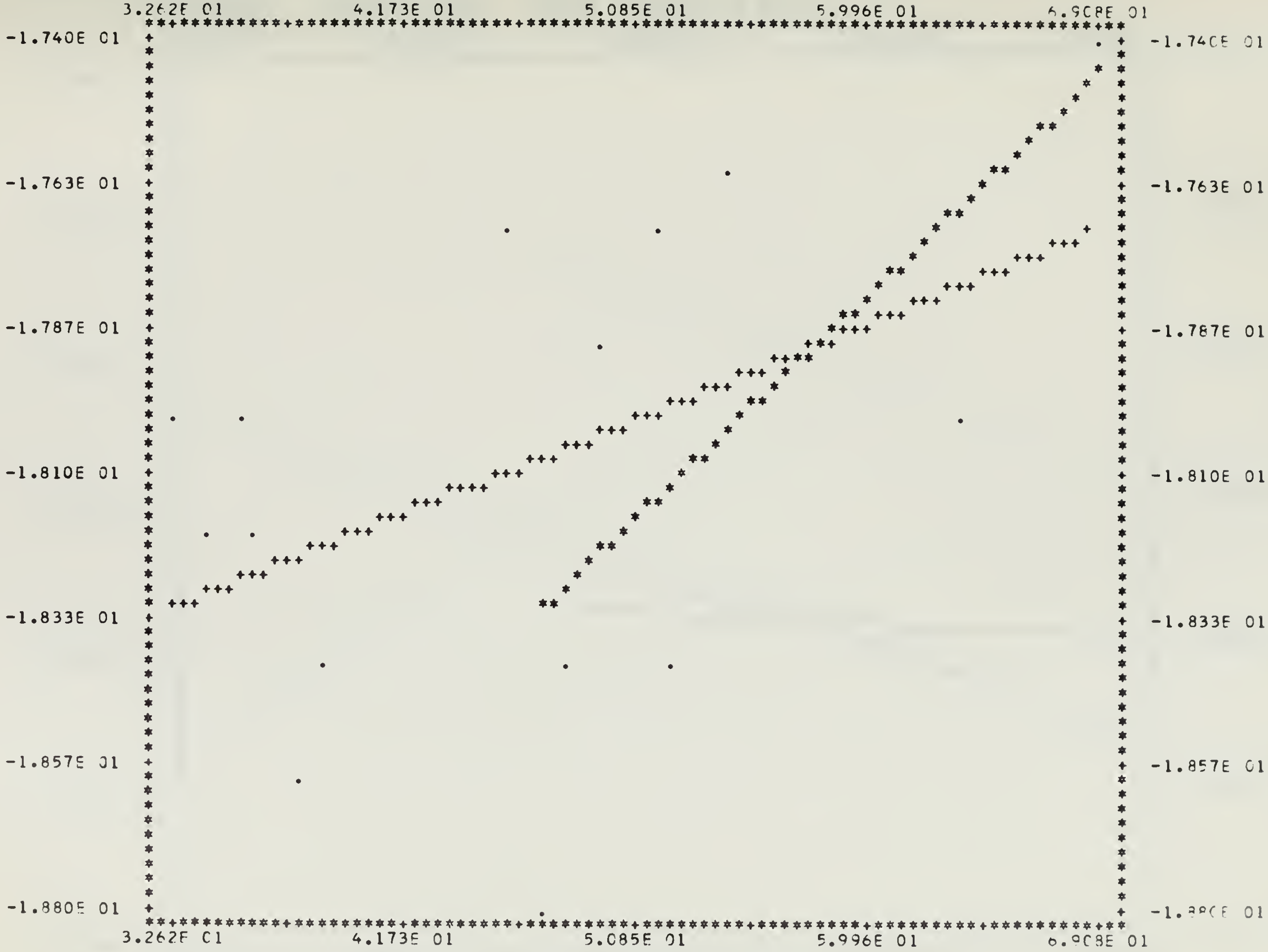
```
1932-1969     STD DEV  0.66     TREND   0.02804 FT PER YR
1947-1969     STD DEV  0.43     TREND   0.07817 FT PER YR
```

GRID POINT 32



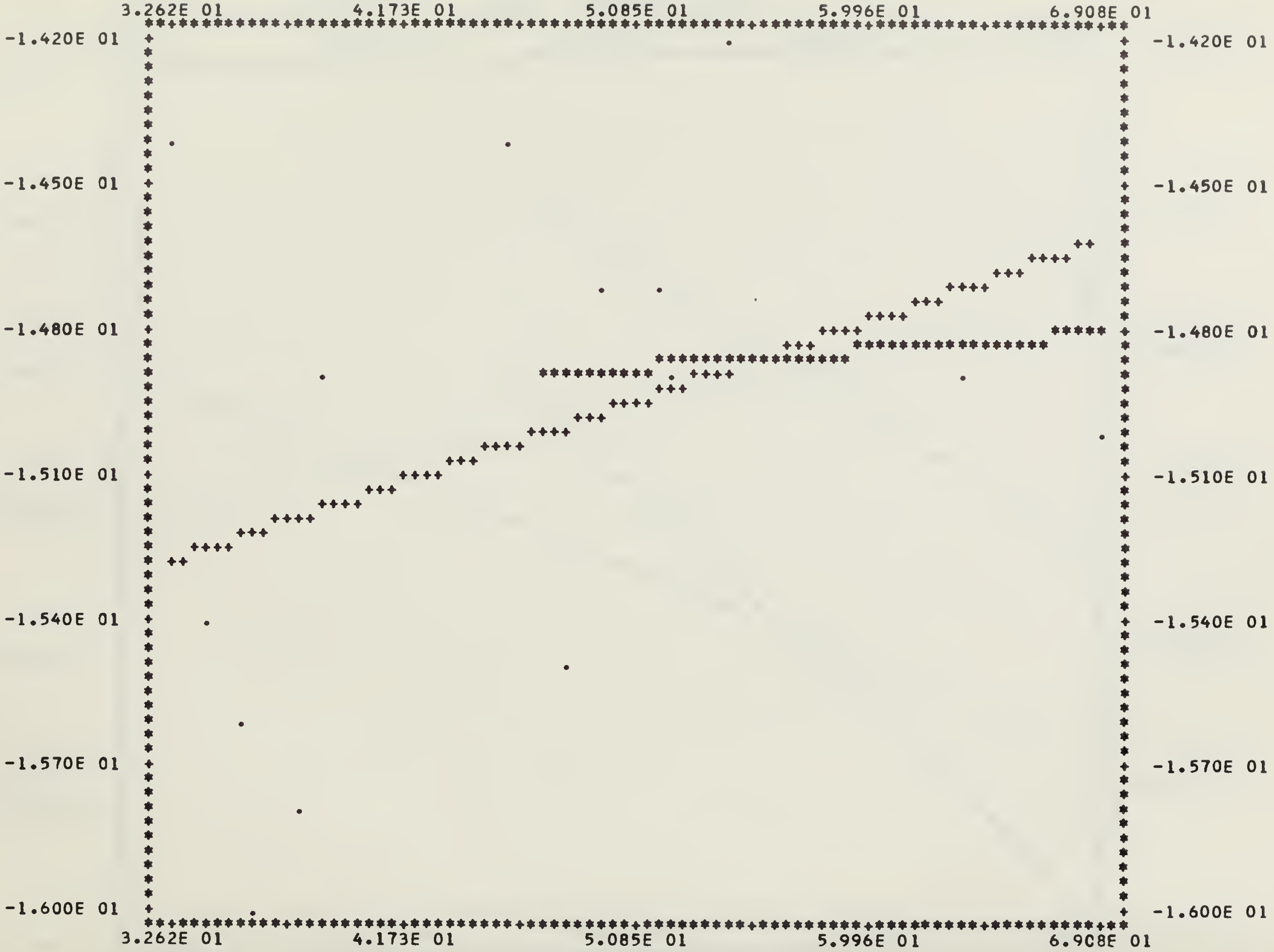
1932-1969 STD DEV 0.40 TREND 0.00974 FT PER YR
1947-1969 STD DEV 0.25 TREND -0.02770 FT PER YR

GRID POINT 33



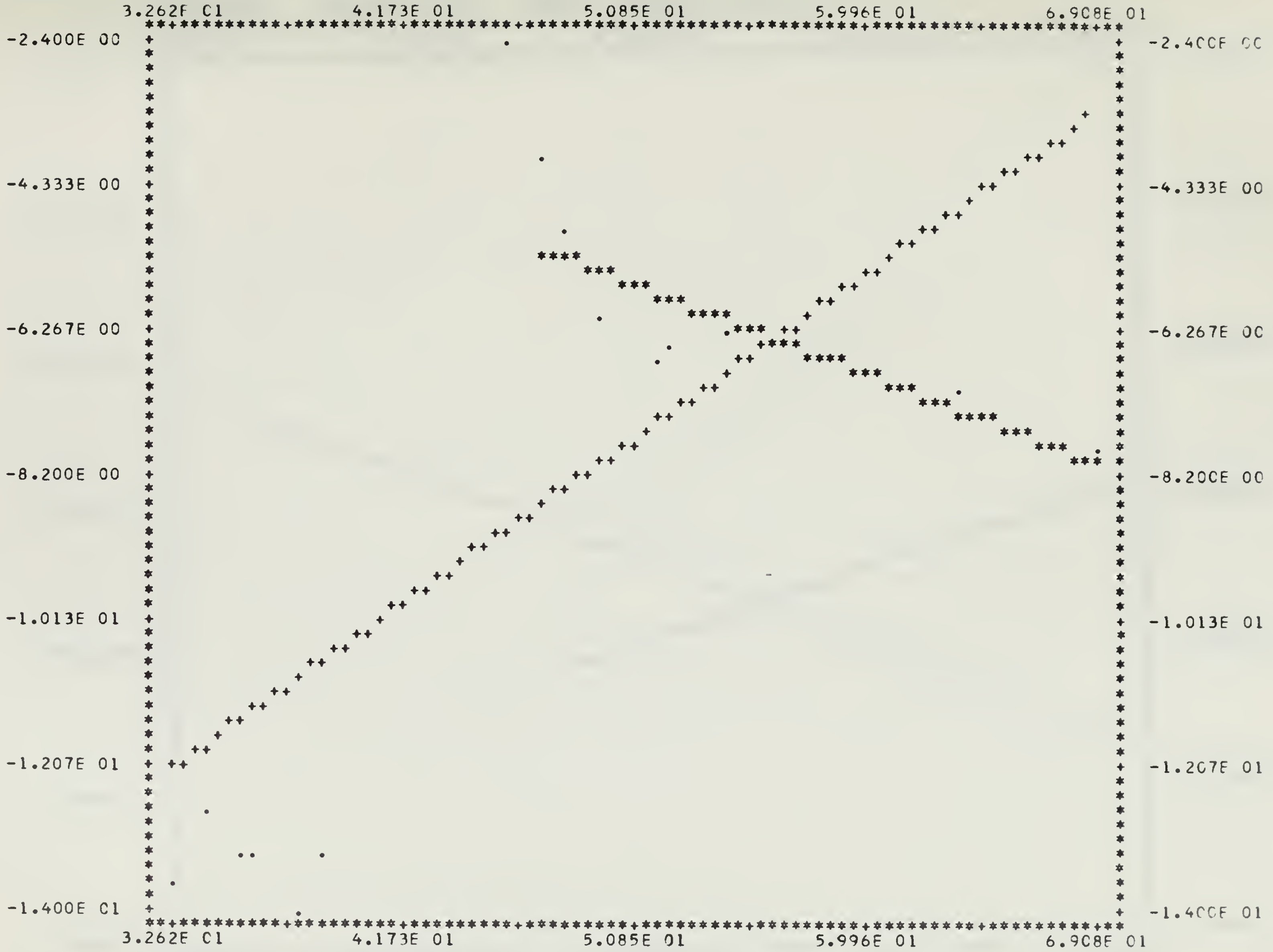
```
1932-1969     STD DEV  0.35     TREND    0.01686 FT PER YR
1947-1969     STD DEV  0.36     TREND    0.03923 FT PER YR
```

GRID POINT 34



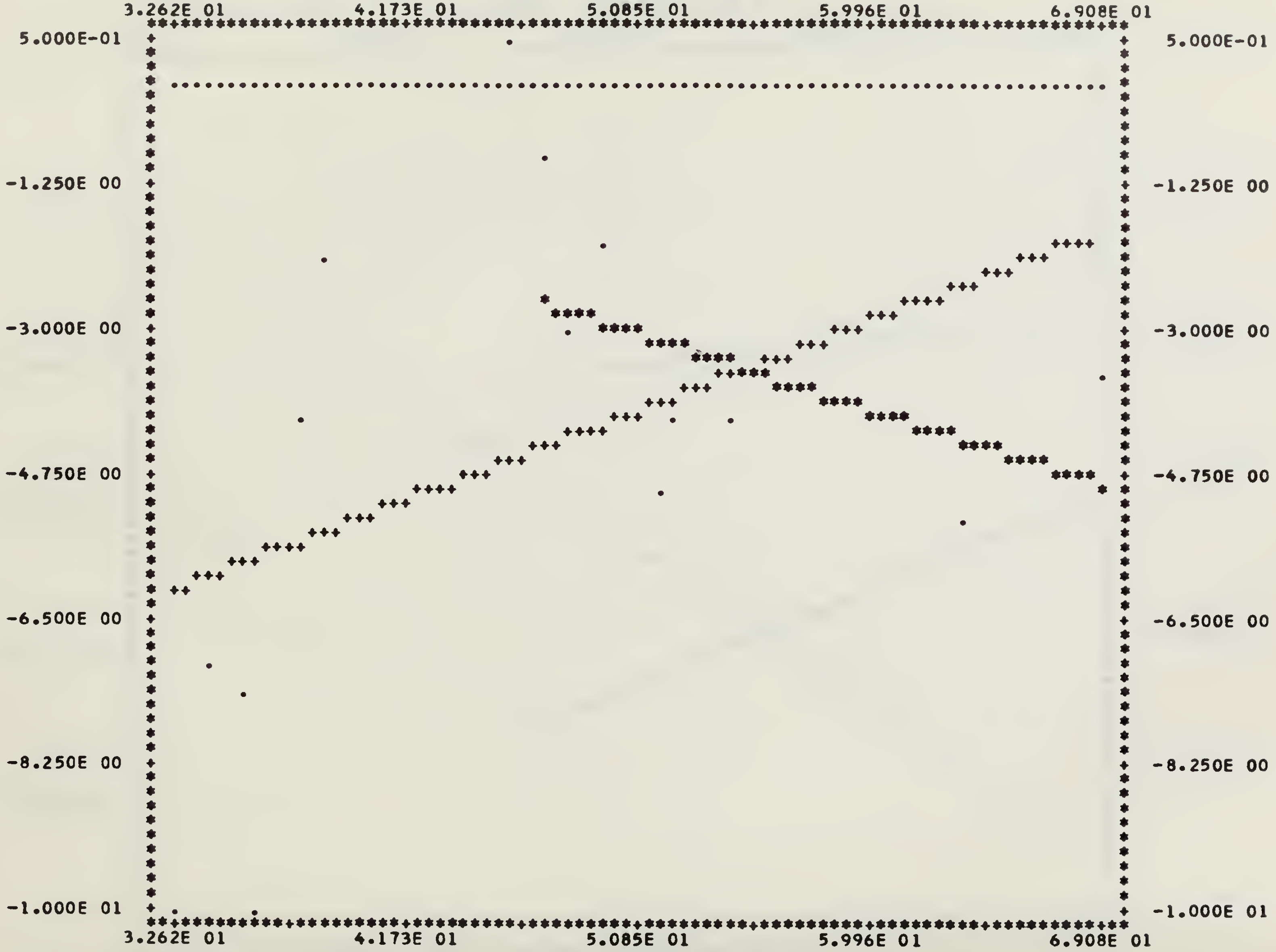
```
1932-1969     STD DEV  0.49      TREND    0.01818 FT PER YR
1947-1969     STD DEV  0.37      TREND    0.00379 FT PER YR
```

GRID POINT 35



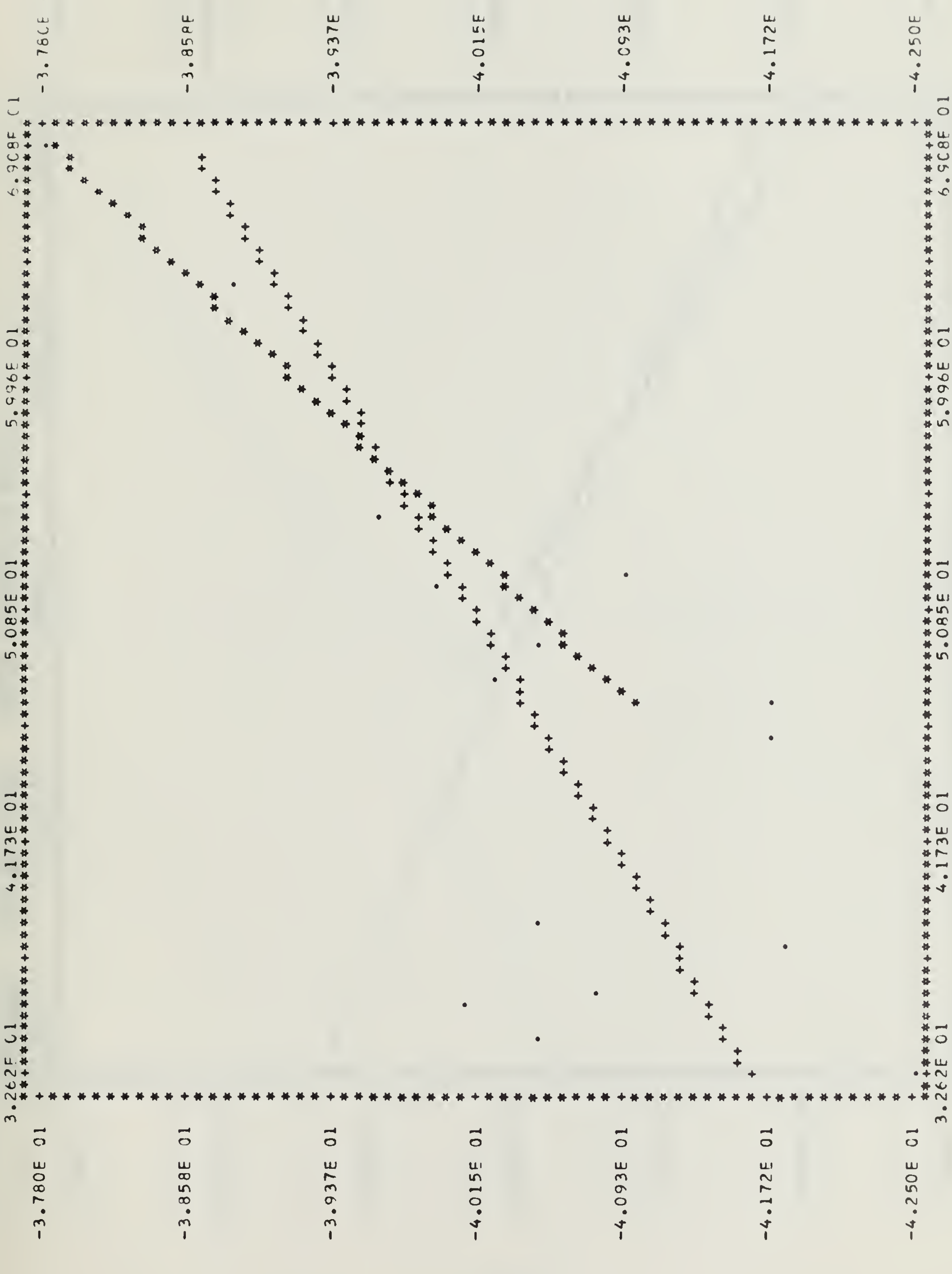
```
1932-1969     STD DEV  3.01     TREND   0.24092 FT PER YR
1947-1969     STD DEV  0.65     TREND  -0.12997 FT PER YR
```

GRID POINT 36



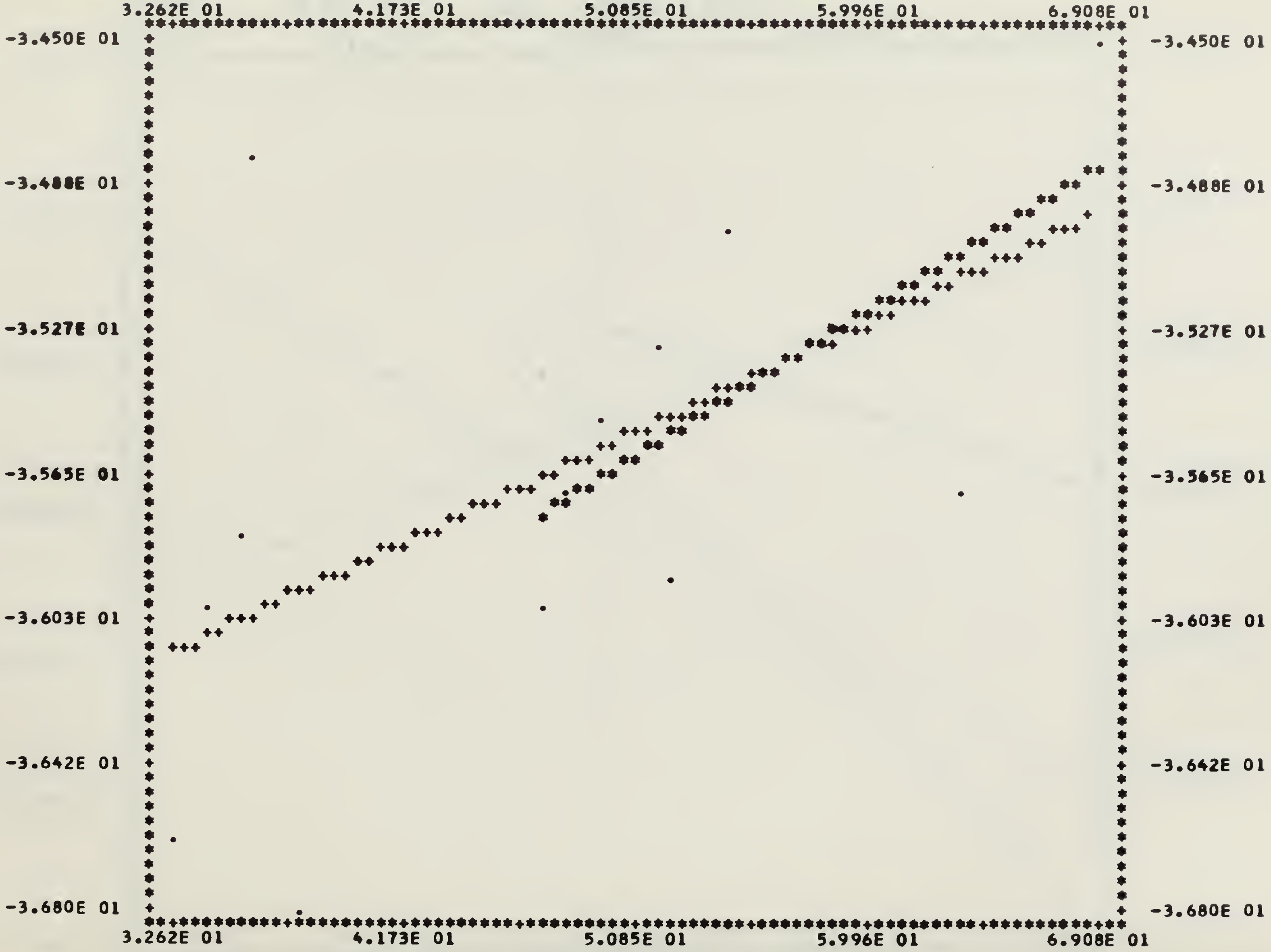
```
1932-1969      STD DEV  2.74      TREND    0.11872 FT PER YR
1947-1969      STD DEV  1.24      TREND   -0.09695 FT PER YR
```

GRID POINT 37



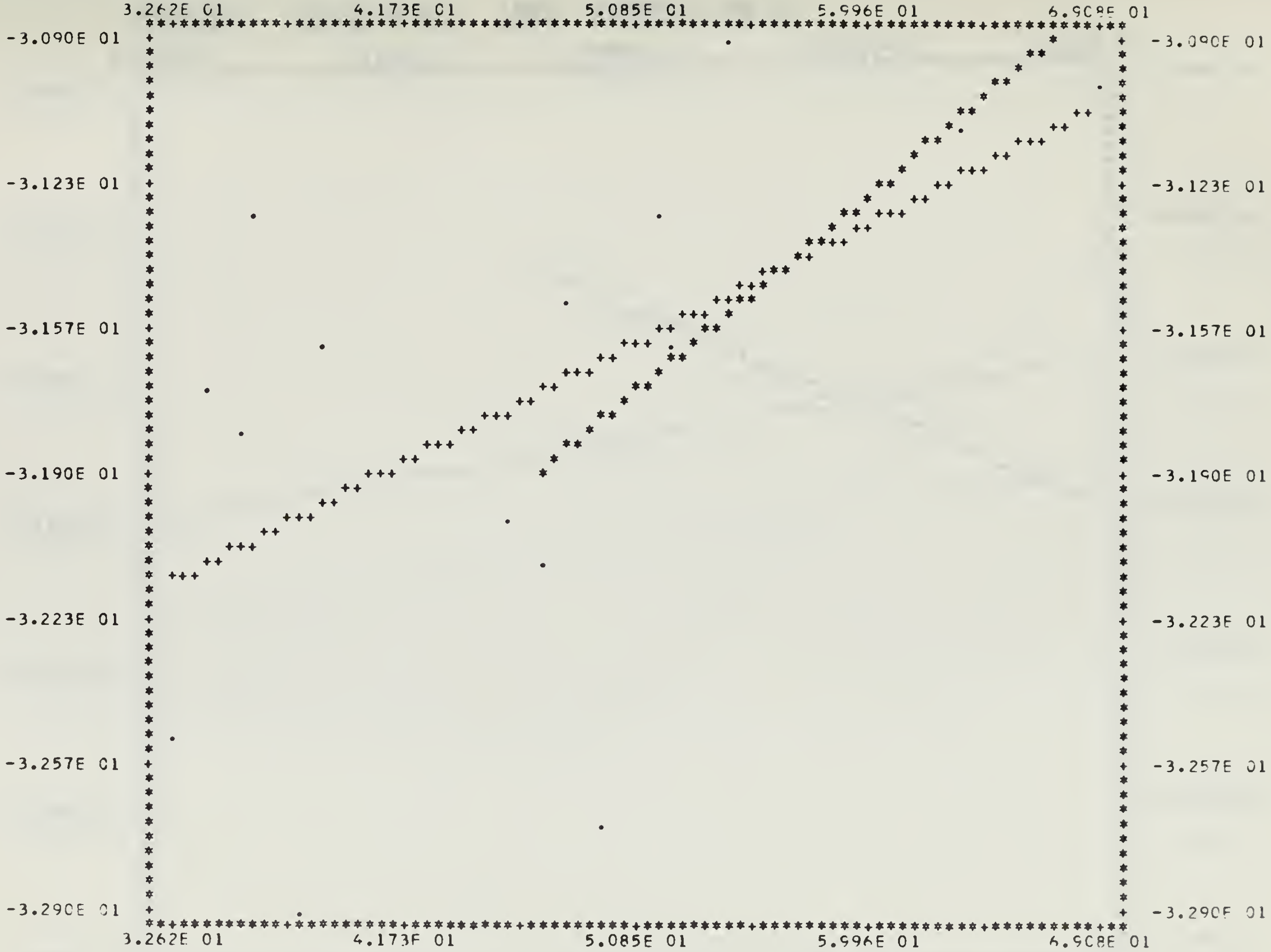
1932-1969 STD DEV 0.81 TREND 0.08222 FT PER YR
1947-1969 STD DEV 0.49 TREND 0.14250 FT PER YR

GRID POINT 38



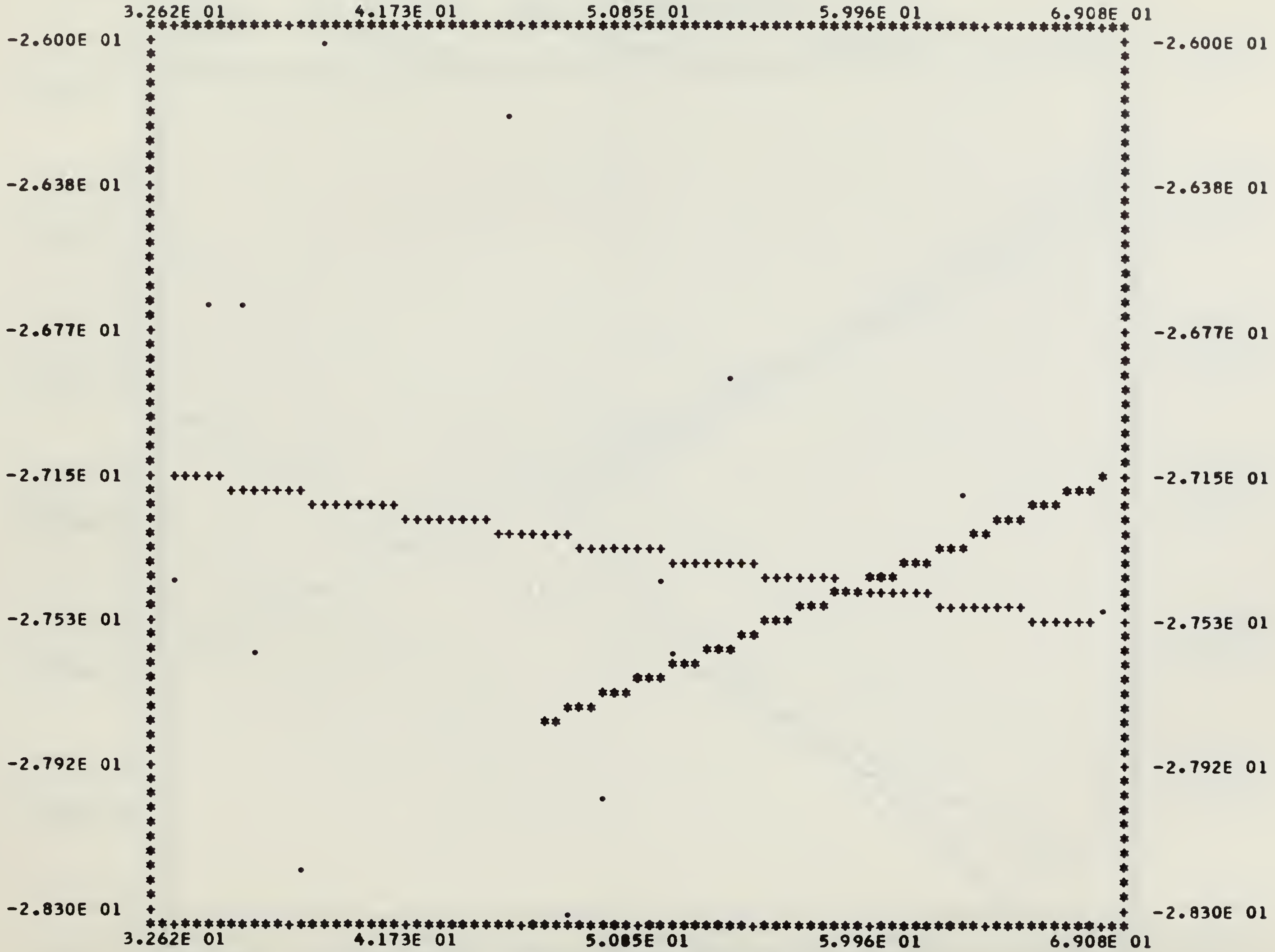
```
1932-1969     STD DEV  0.50     TREND    0.03189 FT PER YR
1947-1969     STD DEV  0.38     TREND    0.04223 FT PER YR
```

GRID POINT 39

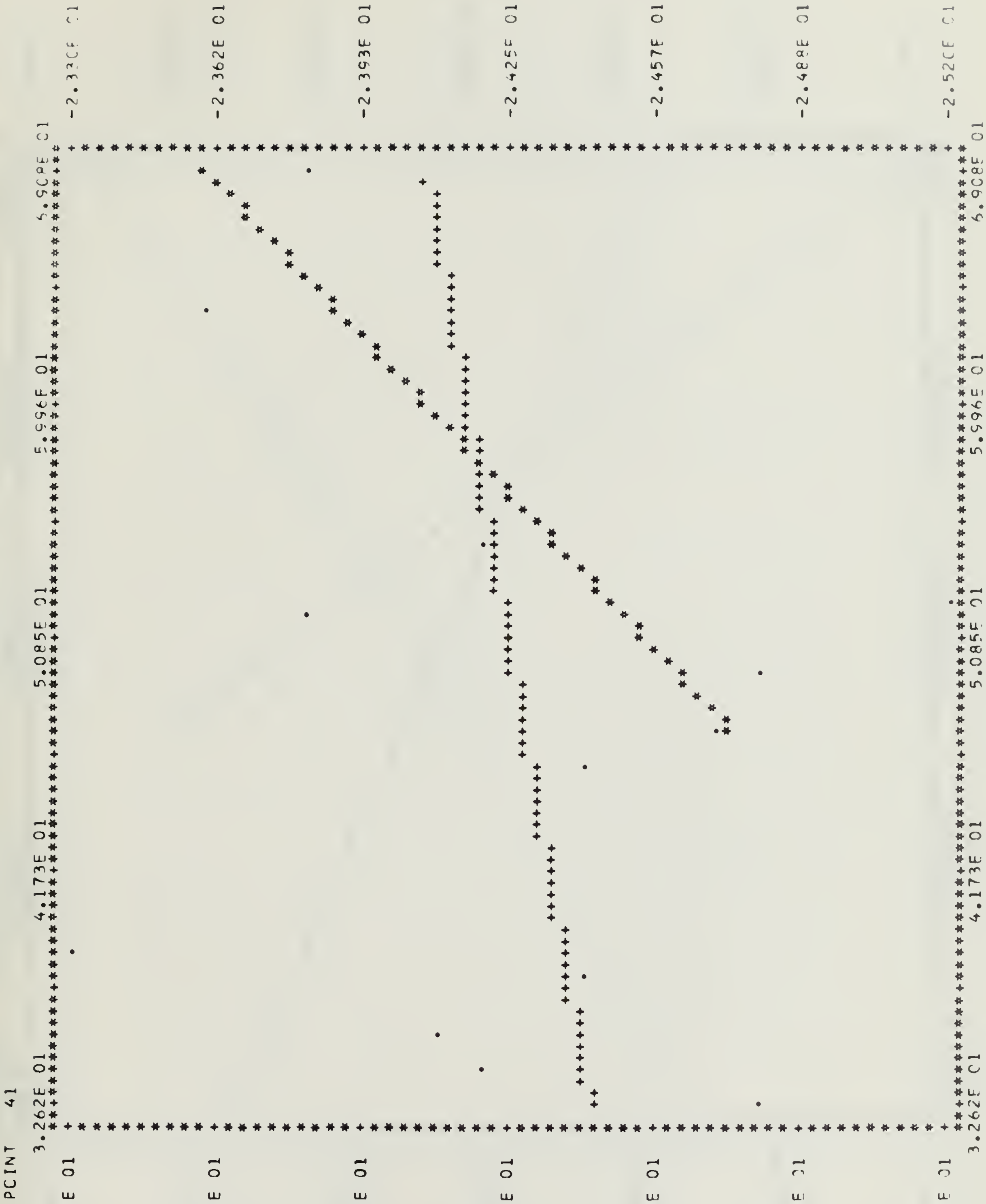


1932-1969 STD DEV 0.51 TREND 0.03016 FT PER YR
1947-1969 STD DEV 0.47 TREND 0.04933 FT PER YR

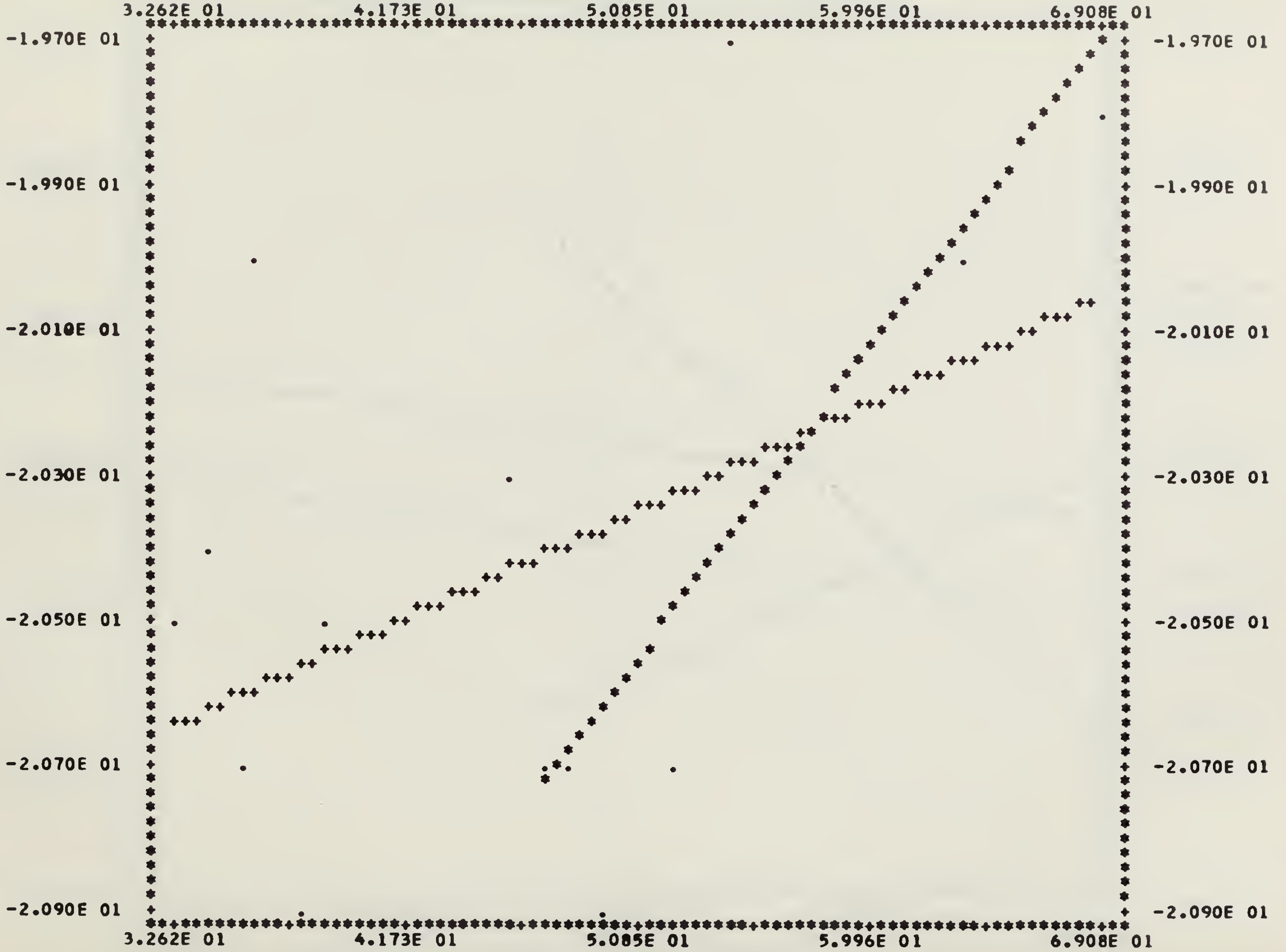
GRID POINT 40



```
1932-1969     STD DEV  0.68      TREND  -0.01098 FT PER YR
1947-1969     STD DEV  0.38      TREND   0.02936 FT PER YR
```

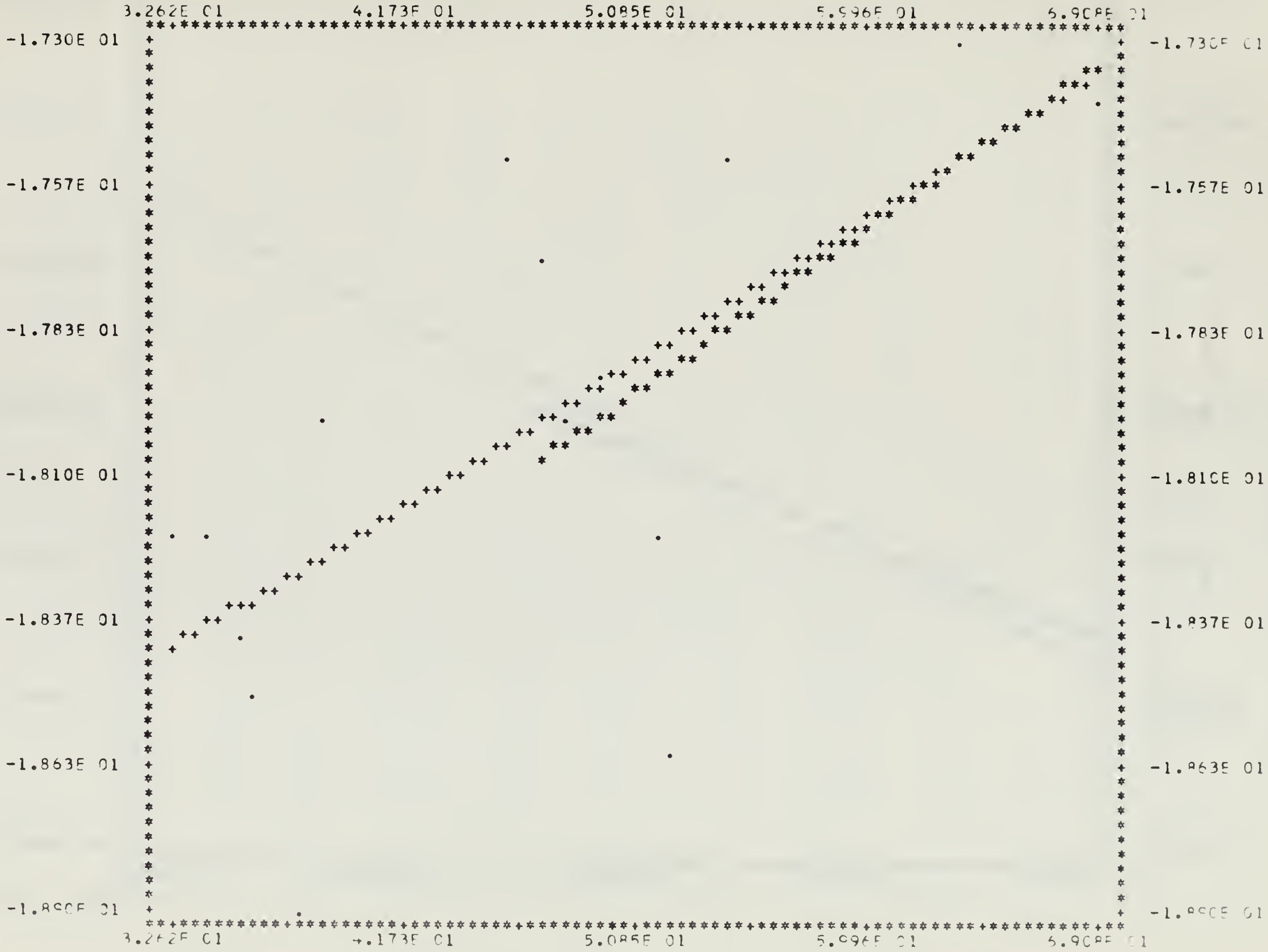

GRID POINT 41
-2.330E 01
-2.362E 01
-2.393E 01
-2.425E 01
-2.457E 01
-2.488E 01
-2.520E 01
3.262E 01
4.173E 01
5.085E 01
5.996E 01
6.908E 01
1932-1969 STD DEV 0.50 TREND 0.00998 FT PER YR
1947-1969 STD DEV 0.41 TREND 0.05189 FT PER YR

GRID POINT 42



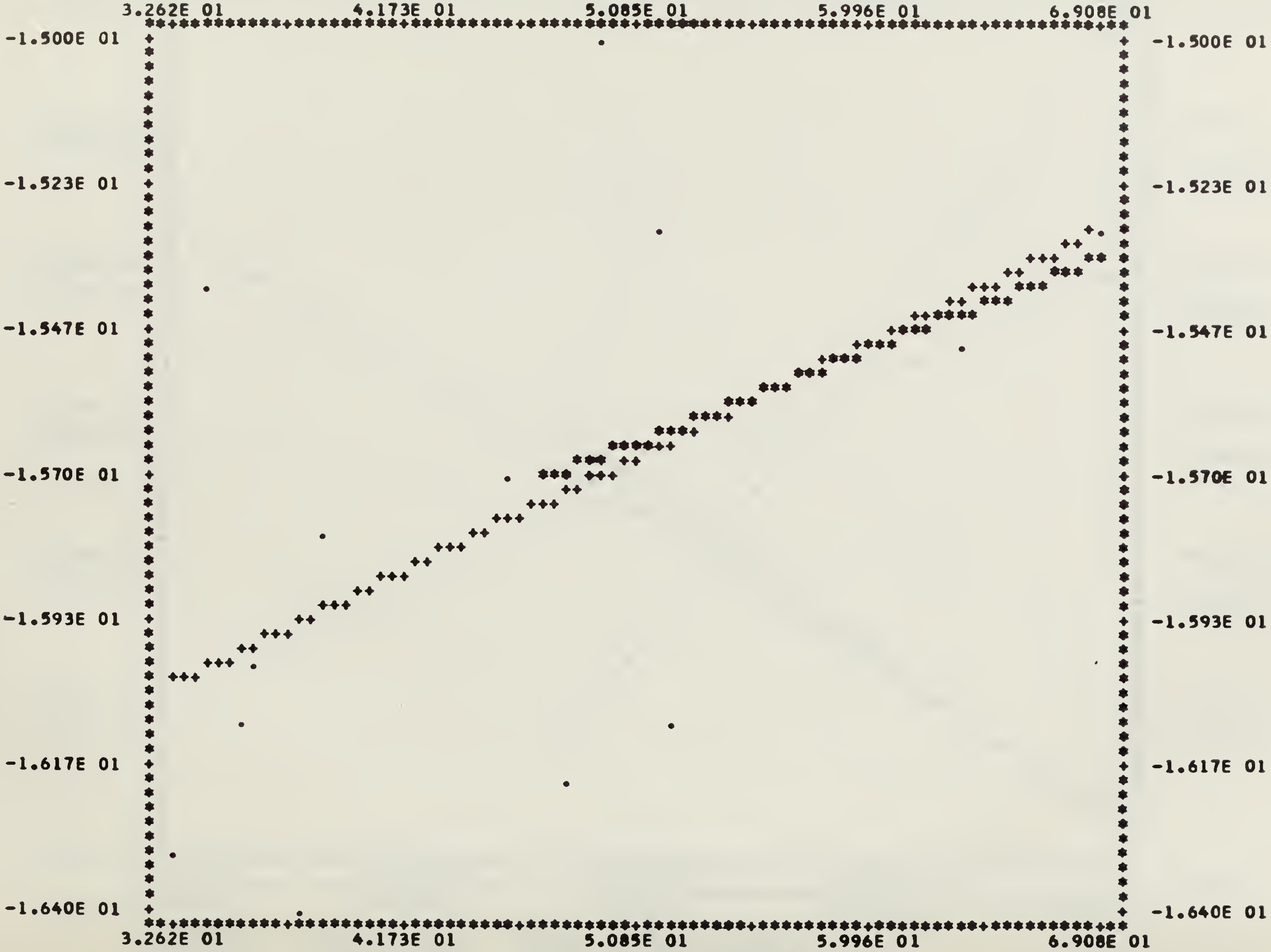
```
1932-1969     STD DEV  0.34     TREND    0.01630 FT PER YR
1947-1969     STD DEV  0.29     TREND    0.04673 FT PER YR
```

GRID POINT 43



1922-1969 STD DEV 0.35 TREND 0.02932 FT PER YR
1947-1969 STD DEV 0.35 TREND 0.03323 FT PER YR

GRID POINT 44



```
1932-1969     STD DEV  0.35     TREND   0.02011 FT PER YR
1947-1969     STD DEV  0.39     TREND   0.01651 FT PER YR
```

APPENDIX D

LIST OF CHARTS OF MONTEREY HARBOR: 1851 to 1969

A list of the 56 hydrographic charts examined during the course of this study are presented herein. The charts marked with an asterisk (*) are those used for the surveys shown in Appendix A and for the comparisons shown in Appendix B.

LIST OF CHARTS OF MONTEREY HARBOR: 1856 to 1969

Corps of Engineers, U. S. Army, 1927
Re-examination of Monterey Harbor, California
Dwg. No. 6-2-10

Corps of Engineers, U. S. Army, 1928
Resurvey of Monterey Harbor, California
Dwg. No. 6-2-11

Corps of Engineers, U. S. Army, 1931
Breakwater at Monterey Harbor, California
Dwg. No. 6-9-5

Corps of Engineers, U. S. Army, 1932*
Monterey Harbor, California
Dwg. No. 6-2-12, 3 sheets

Corps of Engineers, U. S. Army, 1934
Monterey Harbor, California
Comparison of depth contours, Surveys of Oct 1931 and Mar 1934
Dwg. No. 6-20-8

Corps of Engineers, U. S. Army, 1935*
Survey of March 14-15 1934, Monterey Harbor
Dwg. No. 6-2-13

Corps of Engineers, U. S. Army, 1935*
Survey of July 29-31 1935, Monterey Harbor, California
Dwg. No. 6-2-14

Corps of Engineers, U. S. Army, 1935*
Survey of Oct 2-5 1935, Monterey Harbor, California
Dwg. No. 6-2-15

Corps of Engineers, U. S. Army, 1937*
Annual Survey, Monterey Harbor, California
Dwg. No. 6-2-16

Corps of Engineers, U. S. Army, 1938
Monterey Harbor, California Dwg. No. 6-1-23

Corps of Engineers, U. S. Army, 1938*
Survey of July 1938, Monterey Harbor, California
Dwg. No. 6-2-17

Corps of Engineers, U. S. Army, 1939
Monterey Harbor, California
Dwg. No. 6-1-24

Corps of Engineers, U. S. Army, 1945*
Monterey Harbor, Survey of Nov 27-Dec 1 1945
Dwg. No. 6-9

Corps of Engineers, U. S. Army, 1946
Monterey Harbor Dredging
Dwg. No. 6-1-32

Corps of Engineers, U. S. Army, 1947*
Monterey Harbor condition survey of Jan-Feb 1947
Dwg. No. 6-12

Corps of Engineers, U. S. Army, 1947
Monterey Harbor, After dredging survey of 4-12 Feb 1947
Dwg. No. 6-1-33

Corps of Engineers, U. S. Army, 1947
Monterey Harbor, Jet probings in harbor area and
soundings adjacent to breakwater
Dwg. No. 6-13

Corps of Engineers, U. S. Army, 1947
Monterey Harbor project condition survey of 4 April 1947
Dwg. No. 6-2-20

Corps of Engineers, U. S. Army, 1948*
Monterey Harbor condition survey of 6-12 Feb 1948
Dwg. No. 6-14 and 6-2-21

Corps of Engineers, U. S. Army, 1949
Monterey Harbor condition survey of 21-23 June 1949
Dwg. No. 6-17

Corps of Engineers, U. S. Army, 1949*
Monterey Harbor condition survey of 21, 22 & 23 June 1949
Dwg. No. 6-18 and 6-2-22

Corps of Engineers, U. S. Army, 1950
Monterey Harbor dredging
Dwg. No. 6-1-35

Corps of Engineers, U. S. Army, 1950
Monterey Harbor, before dredging survey of 28-29 April 1950
Dwg. No. 6-20

Corps of Engineers, U. S. Army, 1950
Monterey Harbor, After dredging survey of 15 and 17 May 1950
Dwg. No. 6-21

Corps of Engineers, U S Army, 1950
High water shore line changes
Dwg. No. 6-21-1, Plate 7-1, App IV

Corps of Engineers, U. S. Army, 1950
High water shore line changes
Dwg. No. 6-21-2, Plate 7-2, App IV

Corps of Engineers, U. S. Army, 1950
Monterey Bay, Offshore depth changes
Dwg. No. 6-21-3, Plate 8-1, App IV

Corps of Engineers, U. S. Army, 1950
Comparison of depth curves from condition surveys of
Oct 1931, July 1938 and Dec 1945
Dwg. No. 6-21-4, Plate 8-2, App IV

Corps of Engineers, U. S. Army, 1951*
Monterey Harbor condition survey of 29 Sept and 1 Oct 1951
Dwg. No. 6-22 and 6-2-23

Corps of Engineers, U. S. Army, 1952
Survey report on Monterey Harbor,
Plan of Improvement of Monterey Harbor
Dwg. No. 6-1-37

Corps of Engineers, U. S. Army, 1952*
Monterey Harbor condition survey of 20, 21, and 22 May 1952
Dwg. No. 6-23 and 6-2-24

Corps of Engineers, U. S. Army, 1953
Monterey Harbor dredging
Dwg. No. 6-1-38

Corps of Engineers, U. S. Army, 1953
Monterey Harbor, Before dredging survey of 14 May 1953
Dwg. No. 6-24

Corps of Engineers, U. S. Army, 1953
Monterey Harbor, After dredging survey of 7, 9 Aug 1953
Dwg. No. 6-25 and 6-2-25

Corps of Engineers, U. S. Army, 1954*
Monterey Harbor, Condition survey of 3 and 4 Aug 1954
Dwg. No. 6-26 and 6-2-26

Corps of Engineers, U. S. Army, 1955
Monterey Harbor, Reconnaissance Survey of 28, 29 Sept 1955
Dwg. No. 6-27

Corps of Engineers, U. S. Army, 1956
Monterey Harbor, Condition survey of 26, 27 Nov 1956
Dwg. No. 6-28

Corps of Engineers, U. S. Army, 1957
Monterey Harbor dredging
Dwg. No. 6-1-39

Corps of Engineers, U. S. Army, 1957
Monterey Harbor before dredging survey of 2 Apr 1957
Dwg. No. 6-29

Corps of Engineers, U. S. Army, 1957
Monterey Harbor after dredging survey of 5 and 6 June 1957
Dwg. No. 6-2-27

Corps of Engineers, U. S. Army, 1958
Monterey Harbor, Plan of Improvement
Dwg. No. 6-1-40

Corps of Engineers, U. S. Army, 1958
Monterey Harbor, High water shore line changes
Dwg. No. 6-21-5, Plate 7-1, App V

Corps of Engineers, U. S. Army, 1958
Monterey Harbor, High water shore line changes
Dwg. No. 6-21-5, Plate 7-2, App V

Corps of Engineers, U. S. Army, 1958
Monterey Harbor, Off shore depth changes
Dwg. No. 6-21-5, Plate 8-1, App V

Corps of Engineers, U. S. Army, 1958
Monterey Harbor, Comparison of depth curves from condition
surveys of Oct 1931 and July 1938 and Dec 1945
Dwg. No. 6-21-5, Plate 8-2, App V

Corps of Engineers, U. S. Army, 1958
Monterey Harbor, Reconnaissance Survey of 8 and 9 May 1958
Dwg. No. 6-30

Corps of Engineers, U. S. Army, 1959
Monterey Harbor, Condition survey of 30 June 1959
Dwg. No. 6-2-28

Corps of Engineers, U. S. Army, 1959
Monterey Harbor, Condition survey of 5 Nov 1959
Dwg. No. 6-2-29

Corps of Engineers, U. S. Army, 1963
Monterey Harbor Model study, Survey of 16-18, 24, 25, 29-31 July,
1 and 2 Aug 1963
Dwg. No. 6-31

Corps of Engineers, U. S. Army, 1963*
Monterey Harbor Topographic & Hydrographic Surveys
from July to Aug 1963
Dwg. No. 6-2-30, 7 sheets

Corps of Engineers, U. S. Army, 1936
Monterey Harbor Topographic & Hydrographic Surveys
from July to Aug 1963 and 15 September 1966
Dwg. No. 6-2-31

Corps of Engineers, U. S. Army, 1966
Monterey Harbor
Dwg. No. 6-5-3, Plates A1, A2

U. S. Coast and Geodetic Survey 1851
Preliminary Survey of the Bay of Monterey
Hydrographic Survey No. H-296

U. S. Coast and Geodetic Survey, 1856
Hydrography of Monterey Bay
Hydrographic Survey No. H-558

U. S. Coast and Geodetic Survey, 1933
Monterey Harbor
Hydrographic Survey No. H-5415

U. S. Coast and Geodetic Survey, 1953-54
Monterey Harbor
Hydrographic Survey No. H-8068

LT Richard J. Lennox, U. S. Navy, 1969*
Monterey Harbor
Hydrographic Survey of January 1969

APPENDIX E

COMPUTER PROGRAMS

The following computer programs were devised to reduce the hydrographic data. These programs are written in FORTRAN IV computer language.

```
**********            PROGRAM  DIFFERENCE            **********
C       THIS PROGRAM DETERMINES THE DIFFERENCE BETWEEN ANY TWO SURVEYS
C       AND THEN UTILIZES SUBROUTINE METMAP TO GIVE A PICTORAL PRE-
C       SENTATION OF THE CHANGE.  CONTOURING INTERVAL IS CONTROLLED IN
C       SUBROUTINE METMAPS CALLING ARGUMENT.  THIS PROGRAM HAS PRINTED
C       DATA CARDS OF THE DEPTH CHANGE AS PART OF THE OUTPUT.

        DIMENSION DEPTH1(60,40),DEPTH2(60,40),DEPTH3(60,40),TITLE(24)
        DO 101 I=1,60
        DO 102 J=1,40
        DEPTH1(I,J)=0.0
        DEPTH2(I,J)=0.0
   102  CONTINUE
   101  CONTINUE
        READ(5,200) TITLE
        DO 103 I=1,60
        READ(5,201)(DEPTH1(I,J),J=1,40)
   103  CONTINUE
        DO 104 I=1,60
        READ(5,201)(DEPTH2(I,J),J=1,40)
   104  CONTINUE
C
C       AT THIS POINT  SURTRACT DEPTH2 FROM DEPTH1 INORDER TO GET
C       CONTOURE DEPTH CHANGE  DEPTH3
C
        DO 105 I=1,60
        DO 106 J=1,40
        DEPTH3(I,J)=DEPTH1(I,J)-DEPTH2(I,J)
   106  CONTINUE
   105  CONTINUE
C
C       NOW USING SUBROUTINE METMAP CONTOUR DEPTH CHANGES
C
        CALL METMAP(DEPTH3,60,40,TITLE,1.0,0.01,0.0,0.0,0,1)
        WRITE(6,300)
        WRITE(6,301)
        DO 107 I=1,60
        WRITE(6,302)I,(DEPTH3(I,J),J=1,20)
   107  CONTINUE
        WRITE(6,300)
        WRITE(6,303)
        DO 108 I=1,60
        WRITE(6,302)I,(DEPTH3(I,J),J=21,40)
   108  CONTINUE
C
C       NOW PRODUCE REQUIRED OUTPUT DECK OF DEPTH3
C
```

```
      DO 109 I=1,60
      WRITE(7,304)(DEPTH3(I,J),J=1,40)
  109 CONTINUE
  200 FORMAT(20A4)
  201 FORMAT(10F5.1)
  300 FORMAT(1H1,T25,'DEPTH CHANGES FROM                     ',//)
  301 FORMAT(///,T6,3X,'1',5X,'2',5X,'3',5X,'4',5X,'5',5X,'6',5X,'7',
     *5X,'8',5X,'9',5X,'10',4X,'11',4X,'12',4X,'13',4X,'14',4X,'15',
     *4X,'16',4X,'17',4X,'18',4X,'19',4X,'20')
  302 FORMAT(//2X,I2,T6,20F6.1)
  303 FORMAT(///,T6,3X,'21',4X,'22',4X,'23',4X,'24',4X,'25',
     *4X,'26',4X,'27',4X,'28',4X,'29',4X,'30',4X,'31',4X,'32',
     *4X,'33',4X,'34',4X,'35',4X,'36',4X,'37',4X,'38',4X,'39',4X,'40')
  304 FORMAT(10F5.1)
      RETURN
      END
```

```
**********          PROGRAM      METMAP          **********

C      THIS SUBROUTINE OBTAINED FROM THE  NAVAL POSTGRADUATE SCHOOL
C      COMPUTER LIBRARY PRODUCES CONTOURS OF POINTS WITHIN A SPECIFIED
C      GRID SYSTEM. CALLING ARGUMENTS ARE AS FOLLOWS:
C                  Y = TWO DIMENSIONAL FIELD TO BE CONTOURED
C                  N = NUMBER OF ROWS I IN THE ARRAY
C                  M = NUMBER OF ROWS J IN THE ARRAY
C                  T = TITLE FOR PRINTOUT,96 ALPHANUMERIC CHARACTERS
C                BND = BANDWIDTH DESIRED FOR CONTOUR
C                 AZ = SCALING CONSTANT,THE FIRST THREE NUMBERS
C                      TO THE RIGHT OF THE DECIMAL POINT ARE
C                      PRINTED OUT.
C                 BZ = ADDITIVE CONSTANT - USUALLY 0.0
C               AMIN = MINIMUM VALUE TO BE CONTOURED
C                IJT = 0  MEANS SUBROUTINE WILL COMPUTE MIN VALUE
C               ICON = 1  IF CONTOURING DESIRED
C                    = 0  IF NO CONTOURS DESIRED
C          NOTE: GRID ORIGIN I=1,J=1 IS IN UPPER LEFT HAND CORNER OF
C                GRID: I INCREASES DOWNWARD, J INCREASES TO RIGHT.


      SUBROUTINE METMAP(Y,N,M,T,BND,AZ,BZ,AMIN,IJT,ICON)
      REAL*4 IH,KG,ITJZ                                                 MNMAP001
      DIMENSION A(140),B(140),C(140),D(140),IH(20),Y(N,M),TP(5),XMT(5),
     1BT(5),KG(10),T(24)
C                                                                       MNMAP004
C                                                                       MNMAP005
      DATA DUE/4H    /,EPL/4H+   /,EMI/4H-   /,IH/1H0,1H ,1H1,1H ,1H2,  MNMAP006
     11H ,1H3,1H ,1H4,1H ,1H5,1H ,1H6,1H ,1H7,1H ,1H8,1H ,1H9,1H /,KG/  MNMAP007
     21H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/,BLK/4H    /              MNMAP008
C                                                                       MNMAP009
      YMIN=Y(1,1)
      YMAX=Y(1,1)                                                       MNMAP011
      DO 20 I=1,M                                                       MNMAP012
      DO 10 J=1,N                                                       MNMAP013
      YMIN=AMIN1(YMIN,Y(J,I))                                           MNMAP014
      YMAX=AMAX1(YMAX,Y(J,I))                                           MNMAP015
   10 CONTINUE                                                          MNMAP016
   20 CONTINUE                                                          MNMAP017
      DELY=YMAX-YMIN                                                    MNMAP018
      IF(BND) 25,25,30                                                  MNMAP019
   25 BND=DELY/15.0                                                     MNMAP020
   30 IF (AMIN-YMIN) 31,31,32                                           MNMAP021
   31 IF (IJT) 33,32,33                                                 MNMAP022
   32 PD=YMIN/BND                                                              MNMAP023
      PF=ABS(PD-INT(PD))                                                       MNMAP024
      IF (YMIN) 2,1,1                                                          MNMAP025
    1 AMIN=YMIN-PF*BND                                                         MNMAP026
      GO TO 33                                                                 MNMAP027
    2 AMIN=YMIN-(1.0-PF)*BND                                                   MNMAP028
   33 AHLD=A7                                                                  MNMAP029
      IF(A7) 55,35,55                                                          MNMAP030
   35 SM=AMAX1(ABS(YMIN),ABS(YMAX))                                            MNMAP031
      NS=0                                                                     MNMAP032
   40 NS=NS+1                                                                  MNMAP033
      SM=10.0*SM                                                               MNMAP034
      IF(SM-1.0)40,50,45                                                       MNMAP035
   45 NS=NS-1                                                                  MNMAP036
      SM=SM/10.0                                                               MNMAP037
      IF(SM-1.0)50,50,45                                                       MNMAP038
   50 AHLD=10.0**NS                                                            MNMAP039
   55 HBND=BND/2.0                                                             MNMAP040
      PRINT 70
      PRINT 6,T
    6 FORMAT(5X,24A4,//)
      PRINT 57,AHLD,BZ
   57 FORMAT(1H0,65HTHE FOLLOWING TRANSFORMATION WAS PERFORMED ON THE INMNMAP043
     1PUT MATRIX     /5X,1H(,E12.5,8H*Y(I,J)+,E12.5,1H) //2X,73HAND THREEMNMAP044
     2 DIGITS TO THE RIGHT OF THE DECIMAL POINT ARE PRINTED IN THE MAP )MNMAP045
C                                                                              MNMAP047
      PRINT 54,YMAX,YMIN                                                       MNMAP050
   54 FORMAT(/4X,5HYMAX=,E15.7,5X,5HYMIN=,F15.7)
      IF (ICON)5,58,5
    5 PRINT 11,BND
   11 FORMAT(2X,17HTHE BAND WIDTH IS,E12.5,6H UNITS //4X,14HCONTOUR LEVE
     1LS          )
      I=0                                                                      MNMAP052
      YTOP=AMIN                                                                MNMAP053
      IF(ABS(YMIN-YMAX)-100.0*BND)53,53,58
   53 YB=YTOP                                                                  MNMAP055
      YTOP=YTOP+BND                                                            MNMAP056
      I=I+1                                                                    MNMAP057
      J=MOD(I,20)                                                              MNMAP058
      ITJ7=IH(J)                                                               MNMAP059
      IF(YB-YMAX)59,58,58
   59 PRINT 61,YB,YTOP,ITJ7                                                    MNMAP061
   61 FORMAT(/4X,E10.3,4H TO ,F10.3,2H =,1X,A1)                                MNMAP062
      GO TO 53                                                                 MNMAP063
   58 NCCP=0
      NCP=0
   60 PRINT 70                                                                 MNMAP064
   70 FORMAT(1H1)                                                              MNMAP066
```

```
      PRINT 6,T
      NLINE=0                                                           MNMAP067
      NCCP=NCP+1                                                        MNMAP068
      NCP=NCP+25
   73 IF(NCP-M)80,80,75                                                 MNMAP070
   75 NCP=M                                                             MNMAP071
   80 J=0                                                               MNMAP072
      NLINE=NLINE+1                                                     MNMAP073
      LLINE=N-NLINE+1                                                   MNMAP074
C  SET UP HEADING                                                       MNMAP075
      IF(NCCP-1) 85,85,90                                               MNMAP076
   85 J=4                                                               MNMAP077
   90 DO 100 I=1,135
      A(I)=BLK                                                          MNMAP079
      B(I)=BLK                                                          MNMAP080
      C(I)=BLK                                                          MNMAP081
      D(I)=BLK                                                          MNMAP082
  100 CONTINUE                                                          MNMAP083
  110 DO 160 L=NCCP,NCP                                                 MNMAP084
      J=J+3                                                             MNMAP085
      KI=L                                                              MNMAP086
      IF(KI-100) 130,120,120                                            MNMAP087
  120 LL=KI/100                                                         MNMAP088
      A(J)=KG(LL+1)                                                     MNMAP089
      KI=KI-100*LL                                                      MNMAP090
      GO TO 135                                                         MNMAP091
  130 A(J)=KG(1)                                                        MNMAP092
  135 J=J+1                                                             MNMAP093
      IF(KI-10) 150,140,140                                             MNMAP094
  140 LL=KI/10                                                          MNMAP095
      A(J)=KG(LL+1)                                                     MNMAP096
      KI=KI-10*LL                                                       MNMAP097
      GO TO 155                                                         MNMAP098
  150 A(J)=KG(1)                                                        MNMAP099
  155 J=J+1                                                             MNMAP100
      A(J)=KG(KI+1)                                                     MNMAP101
  160 CONTINUE                                                          MNMAP102
C  SETUP FIRST ROW OF ARRAY                                             MNMAP103
      GO TO 260                                                         MNMAP104
  170 NLINE=NLINE+1                                                     MNMAP105
      LLINE=N-NLINE+1                                                   MNMAP106
      IF(NLINE-N) 180,180,380                                           MNMAP107
  180 DO 190 I=1,135
      A(I)=BLK                                                          MNMAP109
      B(I)=BLK                                                          MNMAP110
      C(I)=BLK                                                          MNMAP111
      D(I)=BLK                                                          MNMAP112
  190 CONTINUE                                                          MNMAP113
```

```
      IF (ICON)195,260,195
  195 NCY=NCCP-1
      J=1                                                               MNMAP115
      IF(NCY)200,200,210                                                MNMAP116
  200 J=5                                                               MNMAP117
  210 NCY=NCY+1                                                         MNMAP118
      IF(NCY-NCP) 220,220,260                                           MNMAP119
  220 IF(NCY-M) 230,260,260                                             MNMAP120
  230 NLINE=NLINE-1
      YD1=Y(NLINE,NCY)-Y(NLINE+1,NCY)
      YD2=Y(NLINE,NCY+1)-Y(NLINE+1,NCY+1)
      TP(1)=Y(NLINE,NCY)-0.25*YD1
      XMT(1)=Y(NLINE,NCY)-0.5*YD1
      BT(1)=Y(NLINE,NCY)-0.75*YD1
      TP(5)=Y(NLINE,NCY+1)-0.25*YD2
      XMT(5)=Y(NLINE,NCY+1)-0.5*YD2
      BT(5)=Y(NLINE,NCY+1)-0.75*YD2
      NLINE=NLINE+1
      D1=0.25*(TP(5)-TP(1))                                             MNMAP129
      D2=0.25*(XMT(5)-XMT(1))                                           MNMAP130
      D3=0.25*(BT(5)-BT(1))                                             MNMAP131
      DO 240 I=2,4                                                      MNMAP132
      TP(I)=TP(I-1)+D1                                                  MNMAP133
      XMT(I)=XMT(I-1)+D2                                                MNMAP134
      BT(I)=BT(I-1)+D3                                                  MNMAP135
  240 CONTINUE                                                          MNMAP136
      DO 250 I=1,5                                                      MNMAP137
      J=J+1                                                             MNMAP138
      I1=MOD(IFIX((TP(I)-AMIN)/BND),20)+1                               MNMAP139
      I2=MOD(IFIX((XMT(I)-AMIN)/BND),20)+1                              MNMAP140
      I3=MOD(IFIX((BT(I)-AMIN)/BND),20)+1                               MNMAP141
      A(J)=IH(I1)                                                       MNMAP142
      B(J)=IH(I2)                                                       MNMAP143
      C(J)=IH(I3)                                                       MNMAP144
  250 CONTINUE                                                          MNMAP145
      GO TO 210                                                         MNMAP146
  260 NCY=NCCP-1                                                        MNMAP147
      J=0                                                               MNMAP148
      IF(NCY) 265,265,270                                               MNMAP149
  265 J=-1                                                              MNMAP150
      GO TO 330                                                         MNMAP151
  270 NCY=NCY+1                                                         MNMAP152
      IF(NCY-NCP) 280,280,310                                           MNMAP153
  280 J=J+2                                                             MNMAP154
      THLD=AHLD*Y(NLINE,NCY)+B7
      IF(THLD) 285,290,290                                              MNMAP156
  285 D(J)=EMI                                                          MNMAP157
      GO TO 295                                                         MNMAP158
```

```
290  D(J)=EPL                                                          MNMAP159
295  NUM=INT(ABS(THLD-INT(THLD))*1000.0+0.5)                           MNMAP160
     NDS=100                                                           MNMAP161
     DO 300 KK=1,3                                                     MNMAP162
     J=J+1                                                             MNMAP163
     KI=NUM/NDS                                                        MNMAP164
     D(J)=KG(KI+1)                                                     MNMAP165
     NUM=NUM-KI*NDS                                                    MNMAP166
     NDS=NDS/10                                                        MNMAP167
300  CONTINUE                                                          MNMAP168
     GO TO 270                                                         MNMAP169
310  IF(NCP-M) 360,320,320                                             MNMAP170
320  IF(J-127)330,330,360
330  J=J+3                                                             MNMAP172
     KI=NLINE
     IF(KI-100) 340,335,335                                            MNMAP174
335  LL=KI/100                                                         MNMAP175
     D(J)=KG(LL+1)                                                     MNMAP176
     KI=KI-100*LL                                                      MNMAP177
     GO TO 343                                                         MNMAP178
340  D(J)=KG(1)                                                        MNMAP179
343  J=J+1                                                             MNMAP180
     IF(KI-10) 350,345,345                                             MNMAP181
345  LL=KI/10                                                          MNMAP182
     D(J)=KG(LL+1)                                                     MNMAP183
     KI=KI-10*LL                                                       MNMAP184
     GO TO 355                                                         MNMAP185
350  D(J)=KG(1)                                                        MNMAP186
355  J=J+1                                                             MNMAP187
     D(J)=KG(KI+1)                                                     MNMAP188
     IF(NCY-1) 270,270,360                                             MNMAP189
360  IF(NLINE-1)362,362,368
362  PRINT 370,(A(I),I=1,132),(B(IP1),IP1=1,132),(D(IP2),IP2=1,132)
     GO TO 170
368  PRINT 370, (A(I),I=1,132),(B(IP1),IP1=1,132),(C(IP2),IP2=1,132),
    1(D(IP3),IP3=1,132)
370  FORMAT(132A1)
     GO TO 170                                                         MNMAP193
380  DO 390 I=1,135
     A(I)=BLK                                                          MNMAP195
     B(I)=BLK                                                          MNMAP196
     C(I)=BLK                                                          MNMAP197
     D(I)=BLK                                                          MNMAP198
390  CONTINUE                                                          MNMAP199
     J=0                                                               MNMAP200
     IF(NCCP-1) 395,395,400                                            MNMAP201
395  J=4                                                               MNMAP202
400  DO 430 L=NCCP,NCP                                                 MNMAP203
```

```
      J=J+3                                                             MNMAP204
      KI=L                                                              MNMAP205
      IF(KI-100) 410,405,405                                            MNMAP206
  405 LL=KI/100                                                         MNMAP207
      C(J)=KG(LL+1)                                                     MNMAP208
      KI=KI-100*LL                                                      MNMAP209
      GO TO 412                                                         MNMAP210
  410 C(J)=KG(1)                                                        MNMAP211
  412 J=J+1                                                             MNMAP212
      IF(KI-10) 420,415,415                                             MNMAP213
  415 LL=KI/10                                                          MNMAP214
      C(J)=KG(LL+1)                                                     MNMAP215
      KI=KI-10*LL                                                       MNMAP216
      GO TO 422                                                         MNMAP217
  420 C(J)=KG(1)                                                        MNMAP218
  422 J=J+1                                                             MNMAP219
      C(J)=KG(KI+1)                                                     MNMAP220
  430 CONTINUE                                                          MNMAP221
      PRINT 370, (B(IP1),IP1=1,132),(C(IP2),IP2=1,132)
      IF(NCP-M)60,500,500                                               MNMAP223
  500 RETURN                                                            MNMAP224
      END                                                               MNMAP225
```

```
**********             PROGRAM  MAIN  SCAN            **********

C      THIS PROGRAM IS THE MAIN CALLING PROGRAM FOR SUBPROGRAM SCAN, ITS
C      PRIMARY FUNCTION BESIDES CALLING SCAN IS TO READ IN THE VALUES
C      A(X,Y) WHICH ARE THE MATRIX OF POINTS AS TAKEN FROM THE GRID
C      SYSTEM IN USE.  THIS PROGRAM ALSO SETS THE VALUES OF CL(N) WHICH
C      ARE THE CONTOUR LEVELS TO BE PLOTTED.

      DIMENSION A(61,41),CL(30)
      COMMON/LENNOX/ITITLE,LABEL,IJEN,CLEVEL
      REAL*8 ITITLE(12)
      READ(5,12)(ITITLE(I),I=1,12),LABEL
      DO 101 I=1,61
  101 A(I,41)=0.0
      DO 102 J=1,41
  102 A(61,J)=0.0
      CL(1)=1.0
      CL(2)=-1.0
      CL(3)=2.0
      IJEN=1
      DO 103 I=1,60
  103 READ(5,10)(A(I,J),J=1,40)
   10 FORMAT(10F5.1)
      DO 104 L=1,3
      CLEVEL=CL(L)
      CALL SCAN(A,61,41,61,41,CL(L))
  104 CONTINUE
      CALL DRAW(2,XP,0,3,0,LABEL,ITITLE,5.0,5.0,12,0,
     *2,2,8,12,1,LAST)
      WRITE(6,501) LAST
  501 FORMAT (I10 /)
   12 FORMAT(6A8)
      RETURN
      END
```

```
**********            SUBROUTINE     SCAN          **********

C     SUBROUTINE SCAN WAS OBTAINED THROUGH THE COMBINED EFFORTS OF
C     THE NAVAL POST GRADUATE SCHOOL COMPUTER FACILITY AND PROF.JENNINGS
C     OF THE MATHEMATICS DEPARTMENT.  THIS PROGRAM UTILIZES
C     ADDITIONAL SUBPROGRAMS TO PRODUCE A CONTOURED GRAPH ON A CALCOMP
C     PLOTTER.  THE VARIOUS SUBPROGRAMS ARE TRACE,CALC,PLOTT AND DRAW.
C     THE ONLY SUBPROGRAM WHICH REQUIRES ADDITIONAL INFORMATION IS
C     PLOTT.  THE CALLING ARGUMENTS FOR SCAN ARE AS FOLLOWS:
C          AM = MATRIX OF POINTS
C          M = VALUE OF I(MAX) FOR MATRIX A(I,J)
C          N = VALUE OF J(MAX) FOR MATRIX A(I,J)
C          MX = PORTION OF I(MAX) DESIRED ON GRAPH
C          NY = PORTION OF J(MAX) DESIRED ON GRAPH
C          CL = CONTOUR LEVELS



      SUBROUTINE SCAN (AM, M, N, MX, NY, CL)
      DIMENSION AM(MX,NY),REC(900),  X(1800), Y(1800)
      DIMENSION IPT(3,3),INX(8),INY(8)
      COMMON /DAYHOF/ MT,NT,NI,IX,IY,IDX,IDY,ISS,IT,IV,NP,NQ,JT,
     1                PY,REC,CV,     IPT,INX,INY,DL,RA,THE
      COMMON /INTFAC/ X,Y
      D=0.
      R=1.
      TH = 1.570796
      NP=0
      DL=D
      RA=R
      THE=TH
      MT=M
      NT=N
      CV=CL
      IF(IZW-120631) 1,3,1
    1 IPT(1,1)=8
      IPT(1,2)=1
      IPT(1,3)=2
      IPT(2,1)=7
      IPT(2,3)=3
      IPT(3,1)=6
      IPT(3,2)=5
      IPT(3,3)=4
      INX(1)=-1
      INX(2)=-1
      INX(3)=0
      INX(4)=1
      INX(5)=1
      INX(6)=1
      INX(7)=0
      INX(8)=-1
      INY(1)=0
      INY(2)=1
      INY(3)=+1
      INY(4)=+1
      INY(5)=0
      INY(6)=-1
      INY(7)=-1
      INY(8)=-1
      IZW=120631
    3 XT=MT
      DO 58 J=1,900
   58 REC(J)=0
      ISS=0
    2 MT1=MT-1
      DO 110 I=1,MT1
      IF (AM(I,1)-CV) 55,110,110
   55 IF (AM(I+1,1)-CV)110,57,57
   57 IX=I+1
      IY=1
      IDX=-1
      IDY=0
      CALL TRACE (AM,MX, NY)
  110 CONTINUE
      NT1=NT-1
      DO 20 I=1,NT1
      IF (AM(MT,I)-CV) 15,20,20
   15 IF (AM(MT,I+1)-CV) 20,17,17
   17 IX=MT
      IY=I+1
      IDX=0
      IDY=-1
      CALL TRACE (AM,MX, NY)
   20 CONTINUE
   22 DO 30 I=1,MT1
      MT2=MT+1-I
      IF (AM(MT2,NT)-CV) 25,30,30
   25 IF (AM(MT2-1,NT)-CV) 30,27,27
   27 IX=MT2-1
      IY=NT
      IDX=1
      IDY=0
      CALL TRACE (AM,MX, NY)
   30 CONTINUE
```

```
      DO 40 I=1,NT1
      NT2=NT+1-I
      IF (AM(1,NT2)-CV) 35,40,40
   35 IF (AM(1,NT2-1)-CV) 40,37,37
   37 IX=1
      IY=NT2-1
      IDX=0
      IDY=1
      CALL TRACE (AM,MX, NY)
   40 CONTINUE
      ISS=1
      NT1=NT-1
      MT1=MT-1
      DO 10 J=2,NT1
      DO 10 I=1,MT1
      IF (AM(I,J)-CV) 5,10,10
    5 IF (AM(I+1,J)-CV) 10,7,7
    7 COM=100*(I+1)+J
      IF (NP) 12,11,12
   12 DO 9 ID= 1,NP
      IF (REC(ID)-COM) 9,10,9
    9 CONTINUE
   11 IX= I+1
      IY=J
      IDX=-1
      IDY=0
      CALL TRACE (AM,MX, NY)
   10 CONTINUE
      RETURN
      END
```

```
**********            SUBROUTINE    TRACE            **********
C     THIS SUBROUTINE IS PART OF SCAN AND REQUIRES NO ALTERATIONS.


      SUBROUTINE TRACE (AM,MY,NY)
      DIMENSION AM(MY,NY),REC(900),  X(1800), Y(1800)
      DIMENSION IPT(3,3), INX(8),INY(8)
      COMMON /DAYHOF/ MT,NT,NI,IX,IY,IDX,IDY,ISS,IT,IV,NP,N ,JT,
     1               PY,REC,CV,     IPT,INX,INY,DL,RA,THE
      COMMON /INTFAC/ X,Y
      PY=0.0
      RC=  COS (THE)*RA
      RS=  SIN (THE)*RA
  501 JT=0
      N=0
      IXC=IX
      IYC=IY
      ISX=IDX+2
      ISY=IDY+2
      IS=IPT(ISX,ISY)
      JTB=0
      ISC=IS
      IF(ISO-8)18,18,17
   17 ISC=ISO-8
   18 IT=0
    5 CONTINUE
      CALL CALC   (AM,MY,NY)
      NZ=N
      N=NZ
      IF (IT+JT-1) 49,49,47
   47 XS=X(N-1)
      YS=Y(N-1)
      X(N-1)=X(N)
      Y(N-1)=Y(N)
      X(N)=XS
      Y(N)=YS
   49 IS=IS+1
      JT=IT
    9 IF (IS-9) 8,7,7
    7 IS=IS-8
    8 IDX=INX(IS)
      IDY=INY(IS)
      IX2=IX+IDX
      IY2=IY+IDY
      JTB=JTB+1
      IF (JTB-1799) 51,51,308
  308 PRINT                   103,CV,X(N),Y(N)
  103 FORMAT(1H0,23HA CONTOUR LINE AT LEVEL,E12.5,21H WAS TERMINATED AT
     1X=,E12.5,3H Y=,E12.5/
     2 48H BECAUSE IT CONTAINED MORE THAN 1799 PLOT POINTS  )
      RETURN
C
C   SHOULD TEST HERE FOR MAXIMUM NUMBER OF PLOTTABLE POINTS IN SEGMENT.
   51 CONTINUE
      IF (ISS) 10,10,20
   20 IF(IX-IX0) 12,21,12
   21 IF(IY-IY0) 12,22,12
   22 IF(IS-IS0) 12,23,12
   23 CONTINUE
      CALL CALC  (AM,MY,NY)
      GO TO 73
   10 IF(IX2) 13,50,13
   13 IF (IX2-MT) 19,19,50
   19 IF (IY2) 11,50,11
   11 IF (IY2-NT) 12,12,50
   12 IF (CV-AM(IX2,IY2)) 206,206,5
  206 IF (IDX**2+IDY**2-1) 213,6,213
  213 DCP=(AM(IX,IY)+AM(IX2,IY)+AM(IX,IY2)+AM(IX2,IY2))/4.0
      IF (DCP-CV) 5,217,217
  217 IF (INX(IS-1)) 214,215,214
  214 IX=IX+IDX
      IDX=-IDX
      PY=2.0
      CALL CALC  (AM,MY,NY)
      IX=IX+IDX
      GO TO 6
  215 IY=IY+IDY
      IDY=-IDY
      PY=2.0
      CALL CALC  (AM,MY,NY)
      IY=IY+IDY
    6 IF (AM(IX-1,IY) - CV) 306,16,16
  306 NP=NP+1
      REC(NP)=100*IX+IY
   16 IS=IS+5
      IX=IX2
      IY=IY2
      GO TO 9
   50 XT=MT
      IF (AM(IX-1,IY)-CV) 307,73,73
  307 NP=NP+1
      REC(NP)=100*IX+IY
```

```
73 DO 74 I=1,N
   X(I)=X(I)+RC*Y(I)
74 Y(I)=RS*Y(I)
   CALL PLOTT (N)
   RETURN
   END
```

```
**********              SUBROUTINE      CALC            **********

C      THIS SUBROUTINE IS PART OF SCAN AND REQUIRES NO ALTERATIONS.



       SUBROUTINE CALC  (AM,MY,NY)
       DIMENSION AM(MY,NY),REC(900),  X(1800), Y(1800)
       DIMENSION IPT(3,3),INX(8),INY(8)
       COMMON /DAYHOF/ MT,NT,NI,IX,IY,IDX,IDY,ISS,IT,IV,NP,N ,JT,
      1                PY,REC,CV,     IPT,INX,INY,DL,RA,THE
       COMMON /INTFAC/ X,Y
       IT=0
       N=N+1
       IF (IDX**2 + IDY**2 -1) 20,1,20
     1 IF (IDX) 10,2,10
     2 X(N)=IX
       Z=IY
       IY2=IY+IDY
       DY=IDY
    41 Y(N) = ((AM(IX,IY)-CV)/(AM(IX,IY)-AM(IX,IY2))) *DY + Z
       RETURN
    10 Y(N)=IY
       W=IX
       DX=IDX
       IX2=IX+IDX
    44 X(N) = ((AM(IX,IY)-CV)/(AM(IX,IY)-AM(IX2,IY))) *DX +W
       RETURN
    20 IX2=IX+IDX
       IY2=IY+IDY
       W=IX
       Z=IY
       DX=IDX
       DY=IDY
       DCP=(AM(IX,IY)+AM(IX2,IY)+AM(IX,IY2)+AM(IX2,IY2))/4.0
       IF (PY-2.0) 24,21,24
    24 IF (DCP-CV) 21,21,25
    21 AL=AM(IX,IY)-DCP
    23 V=.5*(AL+DCP -CV)/AL
    27 X(N)=V*DX+W
       Y(N)=V*DY+Z
       PY=0.0
       RETURN
    25 IT=1
       AL=AM(IX2,IY2)-DCP
    33 V=.5*(AL+DCP-CV)/AL
```

```
28  X(N)=-V*DX+W + DX
    Y(N)=-V*DY+Z + DY
    RETURN
    END
```

```
***********            SUBROUTINE    PLOTT            ***********
C      THIS SUBROUTINE IS USED TO DETERMINE THE SCALING REQUIREMENTS
C      FOR A PARTICULAR GRAPH AND TO CALL SUBROUTINE DRAW FROM THE
C      COMPUTER FACILITY LIBRARY.



       SUBROUTINE PLOTT(NP)
       COMMON /INTFAC/ X(1800), Y(1800)
       COMMON/LENNOX/ ITITLE, LABEL, IJEN, CLEVEL
       REAL*8 ITITLE(12)
       REAL*4 LABEL
       DIMENSION XP(1800), YP(1800)
       IF (NP .LE. 900) GO TO 5
       NP = 900
     5 DO 10  I=1,NP
C
C      CONVERT MATRIX NOTATION TO COMPUTER GRID NOTATION, -X IS USED AS
C      ORIGIN IS IN UPPER LEFT HAND CORNER OF GRID.
C
       XP(I)=Y(I)
    10 YP(I)=-X(I)
       WRITE (6, 504)  NP, CLEVEL
       IF (NP - 10) 30, 30, 11
    11 WRITE (6, 502)  (I, XP(I), YP(I),  I=1,NP)
       IF (IJEN - 1) 15, 15, 20
    15 MODCUR = 1
       GO TO 25
    20 MODCUR = 2
    25 CALL DRAW(NP, XP, YP, MODCUR, 0, LABEL, ITITLE, 5.0, 5.0,12,0,
      *2,2,8,12,1,LAST)
       WRITE (6, 501)  LAST
       IJEN = IJEN + 1
   501 FORMAT (I10 /)
   502 FORMAT (4(1X, I3, 2F9.2, 3X))
   504 FORMAT (///,I10,F10.2)
    30 RETURN
       END
```

```
**********          PROGRAM     VOLUME          **********
C     THE PURPOSE OF THIS PROGRAM IS TO COMPUTE THE VOLUME CHANGE FROM
C     SURVEY TO SURVEY FOR EACH 50 X 50 SQUARE IN THE GRID SYSTEM.
C     THIS PROGRAM UTILIZES OUTPUT DECK FROM PROGRAM DIFFERENCE FOR
C     THE INPUT DATA.

C     FIRST COMPUTE AVERAGE HEIGHT FOR GRID SQUARES USING FOUR POINTS

      DIMENSION DEPTH3(60,40),AVGHT(60,40),VOL(60,40)
      DO 101 I=1,60
      READ(5,201)(DEPTH3(I,J),J=1,40)
  201 FORMAT(10F5.1)
  101 CONTINUE
      DO 102 I=1,60
      DO 103 J=1,40
      AVGHT(I,J)=0.0
  103 CONTINUE
  102 CONTINUE
      DO 104 I=1,59
      DO 105 J=1,39
      AVGHT(I,J)=(DEPTH3(I,J)+DEPTH3(I+1,J)+DEPTH3(I,J+1)+DEPTH3(I+1,
     *J+1))/4.0
  105 CONTINUE
  104 CONTINUE
C
C     NOW ZEROIZE ALL GRID SQUARES NOT UTILIZED IN AREA OF INTEREST.
C
      DO 106 J=15,17
      AVGHT(1,J)=0.0
  106 CONTINUE
      DO 107 J=17,20
      AVGHT(2,J)=0.0
  107 CONTINUE
      DO 108 J=20,22
      AVGHT(3,J)=0.0
  108 CONTINUE
      DO 109 J=22,25
      AVGHT(4,J)=0.0
  109 CONTINUE
      DO 110 J=25,27
      AVGHT(5,J)=0.0
  110 CONTINUE
      DO 111 J=27,31
      AVGHT(6,J)=0.0
  111 CONTINUE
      DO 112 J=1,3
      AVGHT(6,J)=0.0
```

```
112 CONTINUE
    DO 113 J=29,32
    AVGHT(7,J)=0.0
113 CONTINUE
    DO 114 I=7,11
    AVGHT(I,3)=0.0
114 CONTINUE
    DO 115 I=7,25
    AVGHT(I,32)=0.0
115 CONTINUE
    DO 116 J=32,37
    AVGHT(25,J)=0.0
116 CONTINUE
    DO 117 J=4,5
    AVGHT(11,J)=0.0
117 CONTINUE
    DO 118 I=12,24
    AVGHT(I,5)=0.0
118 CONTINUE
    DO 119 I=24,28
    AVGHT(I,4)=0.0
119 CONTINUE
    DO 120 I=26,59
    AVGHT(I,37)=0.0
120 CONTINUE
    DO 121 I=28,33
    AVGHT(I,5)=0.0
121 CONTINUE
    DO 122 I=33,35
    AVGHT(I,6)=0.0
122 CONTINUE
    DO 123 I=35,37
    AVGHT(I,7)=0.0
123 CONTINUE
    DO 124 I=37,38
    AVGHT(I,8)=0.0
124 CONTINUE
    DO 125 I=38,39
    AVGHT(I,9)=0.0
125 CONTINUE
    DO 126 I=39,48
    AVGHT(I,10)=0.0
126 CONTINUE
    DO 127 I=48,51
     AVGHT(I,11)=0.0
127 CONTINUE
    DO 128 I=51,53
    AVGHT(I,12)=0.0
```

```
  128 CONTINUE
      DO 129 I=53,54
       AVGHT(I,13)=0.0
  129 CONTINUE
      DO 130 J=14,18
      AVGHT(54,J)=0.0
  130 CONTINUE
      DO 131 J=18,21
      AVGHT(55,J)=0.0
  131 CONTINUE
      DO 132 J=21,24
      AVGHT(56,J)=0.0
  132 CONTINUE
      AVGHT(57,24)=0.0
      DO 133 J=24,29
      AVGHT(58,J)=0.0
  133 CONTINUE
      DO 134 J=29,36
      AVGHT(59,J)=0.0
  134 CONTINUE
C
C     INSERT VARIOUS SUBROUTINES AS REQUIRED TO ZEROIZE SUBSEQUENT
C     GRID SQUARES IF AREAS BEING COMPARED ARE NOT OF SIMILIAR SIZE.
C
      CALL AVGH11(AVGHT)
      CALL AVGH12(AVGHT)
      WRITE(6,299)
      WRITE(6,300)
      DO 139 I=1,60
      WRITE(6,301)I,(AVGHT(I,J),J=1,20)
  139 CONTINUE
      WRITE(6,302)
      DO 140 I=1,60
      WRITE(6,301)I,(AVGHT(I,J),J=21,40)
  140 CONTINUE
  300 FORMAT(///,T6,3X,'1',5X,'2',5X,'3',5X,'4',5X,'5',5X,'6',5X,'7',
     *5X,'8',5X,'9',5X,'10',4X,'11',4X,'12',4X,'13',4X,'14',4X,'15',
     *4X,'16',4X,'17',4X,'18',4X,'19',4X,'20')
  301 FORMAT(//2X,I2,T6,20F6.1)
  302 FORMAT(1H1,T6,3X,'21',4X,'22',4X,'23',4X,'24',4X,'25',
     *4X,'26',4X,'27',4X,'28',4X,'29',4X,'30',4X,'31',4X,'32',
     *4X,'33',4X,'34',4X,'35',4X,'36',4X,'37',4X,'38',4X,'39',4X,'40')
  299 FORMAT(1H1,T50,'AVERAGE HEIGHTS FOR GRID SQUARES')

C     NOW USING COMPUTED VALUES OF AVERAGE HEIGHT COMPUTE THE
C     VOLUME CHANGE FOR EACH GRID SQUARE, GRID SQUARE IS 2500 SQFT.
C
```

```
      DO 141 I=1,60
      DO 142 J=1,40
      VOL(I,J)=AVGHT(I,J)*2500.
  142 CONTINUE
  141 CONTINUE
      WRITE(6,303)
  303 FORMAT(1H1,T50,'VOLUME CHANGE FOR GRID SQUARES')
      WRITE(6,304)
  304 FORMAT(///,T6,4X,'1',9X,'2',9X,'3',9X,'4',9X,'5',9X,'6',9X,'7',
     *9X,'8',9X,'9',9X,'10')
      DO 143 I=1,60
      WRITE(6,305)I,(VOL(I,J),J=1,10)
  143 CONTINUE
      WRITE(6,303)
      WRITE(6,306)
  305 FORMAT(//2X,I2,T6,10F10.1)
  306 FORMAT(///,T6,4X,'11',8X,'12',8X,'13',8X,'14',8X,'15',8X,'16',
     *8X,'17',8X,'18',8X,'19',8X,'20')
      DO 144 I=1,60
      WRITE(6,305)I,(VOL(I,J),J=11,20)
  144 CONTINUE
      WRITE(6,303)
      WRITE(6,307)
  307 FORMAT(///,T6,4X,'21',8X,'22',8X,'23',8X,'24',8X,'25',8X,'26',
     *8X,'27',8X,'28',8X,'29',8X,'30')
      DO 145 I=1,60
      WRITE(6,305)I,(VOL(I,J),J=21,30)
  145 CONTINUE
      WRITE(6,303)
      WRITE(6,308)
  308 FORMAT(///,T6,4X,'31',8X,'32',8X,'33',8X,'34',8X,'35',8X,'36',
     *8X,'37',8X,'38',8X,'39',8X,'40')
      DO 146 I=1,60
      WRITE(6,305)I,(VOL(I,J),J=31,40)
  146 CONTINUE


C     IN ORDER TO COMPARE SURVEYS NOW COMPUTE TOTAL INCREASE OR
C     DECREASE OF VOLUME FOR ENTIRE AREA


      TVOL=0.0
      DO 147 I=1,60
      DO 148 J=1,40
```

```
    TVCL=VOL(I,J)+TVCL
148 CONTINUE
147 CONTINUE
    WRITE(6,309) TVOL
    TVCL2=TVOL/9.0
    WRITE(6,310) TVCL2
309 FORMAT(1H1,T10,'TOTAL VOLUME CHANGE.........',F10.1,' CUBIC FEET')
310 FORMAT(///,T10,'TOTAL VOLUME CHANGE..........',F10.1,'CUBIC YARDS')
    RETURN
    END
```

```
**********           PROGRAM   STATISTIC           **********
C     THIS PROGRAM IS USED TO COMPUTE THE STATISTICAL PARAMETERS
C     DESIRED IE., STANDARD DEVIATION, LEAST SQUARE FIT LINE AND ETC.
C     INPUT FOR THIS PROGRAM IS IN THE FORM OF X(N),Y(N) PLOTTED PAIRS.
C     THIS PROGRAM USES SUBROUTINE  PLOTP TO PRODUCE THE GRAPHICAL
C     OUTPUT.

      DIMENSION X(15),Y(15),R(15),A(2,2),B(2),C(2),V(15),E(80),F(80)
     1,G(80),H(80),Q(15),T(2),S(2)
      READ(5,200)(X(I),I=1,15)
      DO 1 K=1,44
      N=15
      READ(5,201) (Y(I),I=1,15)
      DO 2 I=1,15
      Y(I)=-Y(I)
    2 CONTINUE
      X1=0.0
      DO 3 J=1,15
    3 X1=X1+X(J)
      Y1=0.0
      DO 4 J=1,15
    4 Y1=Y1+Y(J)
      XX=0.0
      DO 5 J=1,15
    5 XX=XX+X(J)**2
      XY=0.0
      DO 6 J=1,15
    6 XY=XY+X(J)*Y(J)
      A(1,1)=N
      A(1,2)=X1
      A(2,1)=X1
      A(2,2)=XX
      B(1)=Y1
      B(2)=XY
      CALL SIMQ(A,B,2,KS)
      C(1)=B(1)
      C(2)=B(2)
      DO 8 I=1,15
    8 V(I)=(C(2)*X(I)-Y(I)+C(1))/(SQRT(C(2)*C(2)+1.0))
      VV=0.0
      DO 11 L=1,15
   11 VV=VV+V(L)**2
      V1=0.0
      DO 12 L=1,15
   12 V1=V1+V(L)
      VAR=(VV-V1**2/N)/(N-1)
      SD=SQRT(VAR)
      E(1)=32.62
      F(1)=C(1)+C(2)*E(1)
      DO 10 I=2,80
      E(I)=E(I-1)+0.45575
      F(I)=C(1)+C(2)*E(I)
   10 CONTINUE
      WRITE(6,300) K
      CALL  PLOTP(X,Y,15,1)
      CALL  PLOTP(E,F,80,2)
      CALL  STAT2(X,Y,G,H,CC,SD2,VAR2)
      CALL  PLOTP(G,H,60,3)
      WRITE(6,301)  SD,C(2),SD2,CC
    1 CONTINUE
  200 FORMAT(15F5.2)
  201 FORMAT(15F5.1)
  300 FORMAT(1H1,/,T15,'GRID POINT    ',I2,/)
  301 FORMAT(/T26,'1932-1969',5X,'STD DEV',F6.2,5X'TREND  ',F8.5,' FT
     1PER YR',/,T26,'1947-1969',5X,'STD DEV',F6.2,5X,'TREND  ',F8.5,' FT
     2PER YR',/)
      RETURN
      END


      SUBROUTINE  STAT2(X,Y,G,H,CC,SD2,VAR2)
      DIMENSION  X(15),Y(15),R(15),A(2,2),B(2),C(2),V(15),E(80),F(80)
     1,G(80),H(80),Q(15)
      N=8
      DO 13  J=1,8
   13 Q(J)=X(J+7)
      DO 14  J=1,8
   14 Y(J)=Y(J+7)
      X1=0.0
      DO 3  J=1,8
    3 X1=X1+Q(J)
      Y1=0.0
      DO 4  J=1,8
    4 Y1=Y1+Y(J)
      XX=0.0
      DO 5  J=1,8
    5 XX=XX+Q(J)**2
      XY=0.0
      DO 6  J=1,8
    6 XY=XY+Q(J)*Y(J)
      A(1,1)=N
      A(1,2)=X1
      A(2,1)=X1
      A(2,2)=XX
      B(1)=Y1
      B(2)=XY
      CALL SIMQ(A,B,2,KS)
      C(1)=B(1)
      C(2)=B(2)
      DO 8 I=1,8
    8 V(I)=(C(2)*Q(I)-Y(I)+C(1))/(SQRT(C(2)*C(2)+1.0))
      VV=0.0
      DO 11 L=1,8
   11 VV=VV+V(L)**2
      V1=0.0
      DO 12 L=1,8
   12 V1=V1+V(L)
      VAR=(VV-V1**2/N)/(N-1)
      SD=SQRT(VAR)
      G(1)=47.08
      H(1)=C(1)+C(2)*G(1)
      DO 10 I=2,49
      G(I)=G(I-1)+0.45575
      H(I)=C(1)+C(2)*G(I)
   10 CONTINUE
      CC=C(2)
      SD2=SD
      VAR2=VAR
      RETURN
      END
```

```
**********           SUBROUTINE    PLOTP          **********
C       THIS SUBROUTINE IS USED IN CONJUNCTION WITH PROGRAM STATISTIC AND
C       PLOTS THE DATA POINTS AND THE VARIOUS LEAST SQUARE LINES CALLED
C       FOR.  VALUES USED IN CALLING STATEMENT ARE:
C                 X = NAME GIVEN TO X AXIS
C                 Y = NAME GIVEN TO Y AXIS
C                NN = NUMBER OF POINTS TO BE PLOTTED
C            MODCUR = SIGNIFYS WHICH CURVE IS BEING PLOTTED IE.,
C                   = 1  THIS IS FIRST CURVE
C                   = 2  THIS IS INTERMEDIATE CURVE
C                   = 3  THIS IS FINAL CURVE


      SUBROUTINE PLOTP(X,Y,NN,MODCUR  )
C***  GUAGE INPUT & FIND MAX & MIN FOR X & Y: CALL UTPLOT
      DIMENSION X(51), Y(51), RANGE(4)
      EQUIVALENCE (RANGE(1),XMAX), (RANGE(2),XMIN),(RANGE(3),YMAX),
     1         (RANGE(4),YMIN)
      IF(MODCUR.EQ.0.OR.MODCUR.EQ.1) GO TO 40
      GO TO 400
   40 XMAX=-1.E20
      XMIN=1.E20
      YMAX=-1.E20
      YMIN=1.E20
      DO 1 I=1,NN
      IF(X(I)-XMAX) 6,6,2
 2    XMAX=X(I)
      YXMAX=Y(I)
 6    IF(X(I)-XMIN) 3,3,7
 3    XMIN=X(I)
      YXMIN=Y(I)
 7    IF(Y(I)-YMAX) 8,8,4
 4    YMAX=Y(I)
      XYMAX=X(I)
 8    IF(Y(I)-YMIN) 5,5,1
 5    YMIN=Y(I)
      XYMIN=X(I)
 1    CONTINUE
  400 IF(MODCUR.EQ.2.OR.MODCUR.EQ.3) GO TO 50
      CALL UTPLOT(X,Y,NN,RANGE,1,MODCUR)
      GO TO 70
   50 CALL UTHOLD(X,Y,NN,RANGE,1,MODCUR)
   70 IF(MODCUR.NE.3)RETURN
      WRITE(6,101) YMAX, XYMAX,YMIN,XYMIN
 101  FORMAT('0MAX Y='1PE12.4,' AT X='E12.4,20X,'MIN Y=' E12.4,' AT X='
     1   E12.4)
      WRITE(6,100) XMAX, YXMAX, XMIN, YXMIN
 100  FORMAT('0MAX X='1PE12.4,' AT Y='E12.4,20X,'MIN X=' E12.4,' AT Y='
     1   E12.4)
      RETURN
      END


      SUBROUTINE UTPLOT (X   ,Y   ,NDATA,RANGE,KK7,MODCUR)
      DIMENSION GRID(61,81),XSCALE(5),YSCALE(7)
      DIMENSION X   (1),Y   (1),RANGE(4)
      INTEGER*2 GRID,BLANK,DOT,XCHAR(4)/1H.,1H+,1H*,1HX/
      DATA DOT,BLANK/Z4B40,Z4040/
C
C     GRID IS THE MATRIX USED TO PLOT THE POINTS
C
      IERR=0
      XMAX=RANGE(1)
      XMIN=RANGE(2)
      YMAX=RANGE(3)
      YMIN=RANGE(4)
C
C     CHECKING X AND Y POINTS AND PLOTTING THOSE OUT OF RANGE
C     AT THE MARGIN
C
      DO 30 I=1,NDATA,KKZ
      IF(X   (I)-XMAX) 205,205,220
 220  X   (I)=XMAX
      IERR=IERR+1
      GOTO 210
 205  IF(X   (I)-XMIN)203,210,210
 203  X   (I)=XMIN
      IERR=IERR+1
 210  IF(Y   (I)-YMAX)215,215,212
 212  Y   (I)=YMAX
      IERR=IERR+1
      GOTO 30
 215  IF(Y   (I)-YMIN)217,  30,30
 217  Y   (I)=YMIN
      IERR=IERR+1
C
  30  CONTINUE
C
C     PLOTTING X AND Y AXIS , IF NECESSARY
C
```

```
      XRANGE=XMAX-XMIN
      YRANGE=YMAX-YMIN
C
C     BLANKING OUT MATRIX-(GRID)
C
      DO 300 I=1,61
      DO 301 JJ=1,81
301   GRID(I,JJ)=BLANK
  300 CONTINUE
      YTEST=YMAX*YMIN
      XTEST=XMAX*XMIN
      IF(XTEST)1,222,222
  222 IF(YTEST)333,444,444
    1 IYAXIS=80.*(-XMIN)/XRANGE+1.5
      DO 40 I=1,61
   40 GRID(I,IYAXIS)=DOT
      GOTO 222
  333 IXAXIS=60.*YMAX/YRANGE+1.5
      DO 60 I=1,81
   60 GRID(IXAXIS,I)=DOT
C
C     PLACING POINTS IN THEIR PROPER GRID POSITIONS
C
      ENTRY UTHOLD(X,Y,NDATA,RANGE,KKZ,MODCUR)
  444 IF(MODCUR.EQ.0.OR.MODCUR.EQ.1)JSET=0
      JSET=JSET+1
      IF(JSET.GT.4) JSET=1
      DO 700 I=1,NDATA,KKZ
      IPTX=60.*(YMAX-Y(I))/YRANGE+1.5
      IPTY=80.*(X(I)-XMIN)/XRANGE+1.5
      IF(IPTX.GT.61.OR.IPTY.GT.81) GO TO 70
      IF(IPTX.LE.0.OR.IPTY.LE.0)GO TO 70
      GRID(IPTX,IPTY) = XCHAR(JSET)
      GO TO 700
   70 IERR=IERR+1
  700 CONTINUE
C
C     COMPUTE PROPER SCALE NUMBERS
C
      IF(MODCUR.EQ.0.OR.MODCUR.EQ.1) GO TO 8000
      IF(MODCUR.EQ.2) RETURN
      GO TO 922
 8000 XINCR=XRANGE/4.
      YINCR=YRANGE/6.
      XSCALE(1)=XMAX
      YSCALE(1)=YMAX
      DO 80 I=2,5
   80 XSCALE(I)=XSCALE(I-1)-XINCR
```

```
      DO 81 I=2,7
   81 YSCALE(I)=YSCALE(I-1)-YINCR
C
C     OUTPUT SECTION WITH GRAPH
C
      IF(MODCUR.EQ.0.OR.MODCUR.EQ.3)GO TO 922
      RETURN
   17 FORMAT(22X,
     1          1P E10.3,4(10X,E10.3)/25X,2H**,8(10H+*********),3H+**)
  922 WRITE(6,17) XSCALE(5),XSCALE(4),XSCALE(3),XSCALE(2),XSCALE(1)
      II=1
      I=0
      DO 101 IK=1,61
      IF(I)91,91,92
   91 WRITE(6,18) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)
   18 FORMAT(13X,1P
     1          E10.3,2X,1H+,1X,81A1,1X,1H+,2X,E10.3)
      II=II+1
      GOTO 102
   92 WRITE(6,19) (GRID(IK,IX),IX=1,81)
   19 FORMAT(25X,1H*,1X,81A1,1X,1H*)
  102 I=I+1
      IF(I-10)101,103,103
  103 I=0
  101 CONTINUE
      WRITE(6,22) XSCALE(5),XSCALE(4),XSCALE(3),XSCALE(2),XSCALE(1)
   22 FORMAT(25X,2H**,8(10H+*********),3H+**/   1P
     1                                      22X,E10.3,4(10X,E10.3))
      IF(IERR) 1000,1000,1001
 1001 WRITE(6,20) IERR
   20 FORMAT(10X 'NUMBER OF POINTS OUT OF RANGE ='   I4)
 1000 RETURN
      END
```

APPENDIX F

MONTEREY HARBOR HYDROGRAPHIC SURVEY OF JANUARY 1969

The hydrographic survey conducted by Lieutenant R. J. Lennox, USN, is contained in the pocket attached to the back cover.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library Naval Postgraduate School Monterey, Calif. 93940	2
3.	Dr.Warren C. Thompson Department of Oceanography Naval Postgraduate School Monterey, Calif. 93940	10
4.	LT Richard J. Lennox, USN Naval Destroyer School, Class 28 U. S. Naval Station Newport, R. I. 02840	5
5.	Naval Weather Service Command Washington Navy Yard Washington, D. C. 20390	1
6.	Commanding Officer Fleet Numerical Weather Central Naval Postgraduate School Monterey, Calif. 93940	1
7.	Commanding Officer and Director Navy Electronics Laboratory Attn: Code 2230 San Diego, Calif. 92152	1
8.	Director, Naval Research Laboratory Attn: Tech. Services Info. Officer Washington, D. C. 20390	1
9.	Department of Oceanography Code 58 Naval Postgraduate School Monterey, Calif. 93940	3
10.	Department of Meteorology Code 51 Naval Postgraduate School Monterey, Calif. 93940	1
11.	Oceanographer of the Navy The Madison Building 732 N. Washington St., Alexandria, Va. 22314	1

		No. Copies
12.	Naval Oceanographic Office Attn: Library Washington, D. C. 20390	1
13.	National Oceanographic Data Center Washington, D. C. 20390	1
14.	Director, Coast & Geodetic Survey Department of Commerce Attn: Office of Hydrography and Oceanography Washington, D. C. 20235	1
15.	Director, Maury Center for Ocean Sciences Naval Research Laboratory Washington, D. C. 20390	1
16.	Office of Naval Research Attn: Geography Branch (Code 414) Department of the Navy Washington, D. C. 20360	1
17.	Office of Naval Research Attn: Geophysics Branch (Code 416) Department of the Navy Washington, D. C. 20360	1
18.	Office of Naval Research Attn: Director, Surface & Amphibious Programs Code 463 Department of the Navy Washington, D. C. 20360	1
19.	Office of Naval Research Attn: Ocean Technology Branch (Code 408T) Department of the Navy Washington, D. C. 20360	1
20.	City of Monterey Public Works Division Monterey, Calif. 93940 Attn: Mr. L. W. McIntyre	2
21.	Library California Division of Mines & Geology Ferry Building San Francisco, Calif. 94111	1
22.	Commanding Officer U. S. Army Corps of Engineers 180 New Montgomery St San Francisco, Calif. 94105 Attn: Mr. Ralph E. Blyberg, Mr. Marshall Blank Mr. Orville T. Magoon and Library	4

		No. Copies
23.	State of California Department of Water Resources PO Box 9137 Sacramento, Calif. 95816 Attn: Mr. Robert Ford	1
24.	Prof. Joe Johnson Department of Civil Engineering 412 Hesse Hall University of California, Berkeley Berkeley, Calif. 94700	1
25.	Mr. Thorndike Saville, Jr., Director Research Division Coastal Engineering Research Center 520 Little Falls Road, N. W. Washington, D. C. 20016	1

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)*

Naval Postgraduate School
Monterey, Calif. 93940

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3 REPORT TITLE

An Investigation of Bottom Changes in Monterey Harbor (1932-1969)

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Thesis for Master of Science Degree, June 1969

5 AUTHOR(S) *(Last name, first name, initial)*

Richard John Lennox

6. REPORT DATE June 1969	7a. TOTAL NO. OF PAGES 182	7b. NO. OF REFS 8

8a. CONTRACT OR GRANT NO. NA	9a. ORIGINATOR'S REPORT NUMBER(S) NA
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* NA
d.	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES NA	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, Calif. 93940

13. ABSTRACT

Bottom changes occurring in Monterey Harbor from 1932-1969 were analyzed by numerical computer methods using 15 selected hydrographic surveys. Results of the study indicate that the major portion of the harbor has been shoaling in the mean since 1932. The long-term shoaling rate has been 0.4 to 4.0 feet per decade in the beach and nearshore zones and along the breakwater; and less than 0.25 feet per decade in the stable outer harbor. The accretion rate averaged 17,500 cubic yards per year from 1932-1969, but only 7,100 cubic yards per year from 1947 to 1969. The shoaling is believed due to the construction of the Coast Guard Breakwater in 1931-1934. It is deduced that prior to 1960 the excess sand was carried into the harbor by littoral transport from Del Monte Beach and by wave currents around the breakwater. Construction of the solid wall on Wharf 2 in 1960 cut off the former sand supply. Local redistribution of sand in the beach and nearshore zones of the harbor is large and results in areas of significant accretion and erosion between surveys. Dredging operations have had only short-term effectiveness because the spoil has been retained within the harbor.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Harbors						
California Harbors						
Monterey Harbor						
Harbor, Sand Problems in						
Hydrographic Surveys, Computer Analysis of						